U.S. Fish & Wildlife Service

Barton Springs Salamander

(Eurycea sosorum)

Draft Recovery Plan

January 2005

DRAFT

BARTON SPRINGS SALAMANDER
(*Eurycea sosorum*)

RECOVERY PLAN

Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

Approved: ___*Draft*____
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U.S. Fish and Wildlife Service. 2004. Draft Recovery Plan for the Barton Springs Salamander (*Eurycea sosorum*). U.S. Fish and Wildlife Service, Albuquerque, NM.

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ACKNOWLEDGMENTS

The U.S. Fish and Wildlife Service gratefully acknowledges the commitment, dedication, and efforts of the Barton Springs Salamander Recovery Team in the preparation of this recovery plan. Without their valuable expertise and assistance, this recovery plan would not have been possible.

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The Service would also like to express its appreciation for the many individuals, groups, and agencies who have been actively working to resolve problems and gather information needed to achieve the goals of stabilizing the habitat and populations of the Barton Springs salamander, and making progress toward recovery. We look forward to continued collaboration to achieve the conservation of these unique resources.

We would also like to acknowledge the work of Matthew Lechner, Lisa O’Donnell, and Krishna Gifford in preparing early drafts of this recovery plan, while they served as the Service Liaison to the recovery team.

EXECUTIVE SUMMARY

Species' Status: The Barton Springs salamander (*Eurycea sosorum*) was federally listed as endangered on May 30, 1997 (62 FR 23377-23392, Service 1997). The U.S. Fish and Wildlife Service (Service) has assigned the salamander a recovery priority number of 2C. No critical habitat has been designated for this species. The Barton Springs salamander is also listed as endangered by the State of Texas.

Habitat Requirements and Limiting Factors: The Barton Springs salamander has only been documented at four spring outlets (collectively known as Barton Springs) within the City of Austin's Zilker Park in Travis County, Texas. Barton Springs salamanders are found in the stenothermal (that is, having a narrow temperature range), flowing water under clean gravel and cobble substrates that are not embedded in sediment, as well as on aquatic plants and in leaf litter. Suitable surface habitat can increase or decrease depending on such factors as springflow, abundance of aquatic plants, sedimentation, water quality, and frequency of floods.

The Final Rule listing the Barton Springs Salamander as endangered (62 FR 23377-23392, Service 1997) identified the primary threats or reasons for listing as "the degradation of the quality and quantity of water that feeds Barton Springs" as a result of urban expansion over the watershed. The restricted range of this species makes it vulnerable to both acute and chronic groundwater contamination. These threats could result in the "destruction, modification, or curtailment of the species habitat or range" through "chronic degradation, catastrophic hazardous materials spills, increased water withdrawals from the Aquifer, and impacts to the surface habitat."

The Final Rule identifies a comprehensive regional plan as a means to protect the Barton Springs salamander from the above mentioned threats. Although such a plan has not been developed, state and local entities, including the City of Austin, have taken actions to protect the salamander and its habitat such as adopting water quality protection ordinances and acquiring thousands of acres of open space in the Barton Springs

watershed. In addition, the Texas Commission on Environmental Quality (TCEQ) oversees a program (the Edwards Rules) in an effort to protect the Edwards Aquifer and aquatic life that depends on the Aquifer. While additional actions may be necessary to ensure the recovery of the Barton Springs salamander, further study is needed regarding the combined effectiveness of the various existing protection efforts. Moreover, a number of interested parties are working on comprehensive regional approaches to aid in the conservation of this resource.

Recovery Goal: The goal of this recovery plan is to ensure the long term viability of the Barton Springs salamander in the wild, allowing initially for reclassification to threatened status and, ultimately, recovery of the species to a point where it is a secure, self-sustaining component of its ecosystem, so that the protections of the Endangered Species Act of 1973, as amended are no longer necessary.

Recovery Criteria:

Reclassify status from endangered to threatened: The Barton Springs salamander should be considered for reclassification when: (1) the Barton Springs watershed is sufficiently protected to maintain adequate water quality (including sediment quality) and ensure the long term survival of the Barton Springs salamander in its natural environment; (2) a plan is implemented to avoid, respond to, and remediate hazardous material spills within the Barton Springs watershed such that the risk of harm to the Barton Springs salamander is insignificant; (3) an Aquifer Management Plan is implemented to ensure adequate water quantity in the Barton Springs watershed and natural springflow at the four spring outlets that comprise Barton Springs; (4) a healthy, self-sustaining natural population of Barton Springs salamanders is maintained; (5) surface management measures to remove local threats to the Barton Springs ecosystem have been implemented; and (6) genetically representative captive breeding populations have been established and a contingency plan is in place to ensure the survival of the species should a catastrophic event destroy the wild population.

Delisting: The Barton Springs salamander should be considered for removal from the List of Endangered and Threatened Wildlife (List) when: (1) the above measures have been implemented and shown to be effective; (2) the Barton Springs salamander population is self-sustaining and stable; and (3) commitments are in place to maintain a genetically representative captive population and to implement the contingency plan and the restoration of salamanders, if needed.

Actions Needed:

1. Protect water quality (including sediment quality) within the Barton Springs watershed.
2. Sustain adequate water quantity at Barton Springs.
3. Manage surface habitat at Barton Springs.
4. Maintain a captive population of Barton Spring salamanders for research and restoration purposes.
5. Develop and implement an outreach plan.
6. Monitor the current salamander populations

Estimated Cost (Dollars x 1000): Cost estimates reflect costs for specific actions needed to promote Barton Springs salamander conservation. Estimates do not include costs that agencies or other entities normally incur as part of their mission or normal operating expenses. The following table provides cost estimates for recovery actions listed in the Implementation Schedule (Section 4.0) of this document. Costs for land acquisition were not included in this figure because the amount of land needed to protect water quality and ensure the recovery of the Barton Springs salamander has not been determined. Furthermore, land costs may change significantly over time.

Total Estimated Cost of Recovery by Recovery Action Priority (Dollars H 1000):

Year	Priority 1(a) Actions	Priority 1(b) Actions	Priority 2 Actions	Priority 3 Actions	Total
1 through 2	795	850	385	105	**2,135**
3 through 4	350	510	215	105	**1,180**
5 through 6	285	290	65	105	**745**
7 through 8	285	290	65	105	**745**
9 through 10	285	290	65	105	**745**
Total	**2,000**	**2,230**	**795**	**525**	**5,550**

Date of Recovery: With a concerted effort to meet all of the recovery criteria, including full cooperation of all partners needed to achieve recovery, reclassifying the status from endangered to threatened could be met within ten years; delisting could be accomplished within ten years following reclassification. Monitoring to ensure recovery criteria have been met should begin prior to reclassification and continue at least five years after delisting.

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1.0 BACKGROUND INFORMATION

1.1 Introduction

The Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*) (ESA) establishes policies and procedures for identifying, listing, and protecting species of wildlife that are endangered or threatened with extinction. The ESA defines an "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." A "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." According to the 1990 U.S. Fish and Wildlife Service's (Service) Recovery Planning Guidelines, recovery is defined as "the process by which the decline of an endangered or threatened species is arrested or reversed, and the threats to its survival are neutralized, so that its long term survival in nature can be ensured". The goal of the recovery process is to restore listed species to a point where they are secure, self-sustaining components of their ecosystem, so that the protections of the ESA are no longer necessary.

The Secretary of the Interior (Secretary) is responsible for administering the ESA's provisions as they apply to this species. Day-to-day management authority for endangered and threatened species under the Department of Interior's jurisdiction has been delegated to the Service. To help identify and guide species recovery needs, section 4(f) of the ESA directs the Service to develop and implement recovery plans for listed species or populations. Recovery plans are strictly advisory documents developed to provide recovery recommendations based on resolving the threats to the species and ensuring self-sustaining populations in the wild. Such plans are to include: (1) a description of site-specific management actions necessary to conserve the species or population; (2) objective, measurable criteria which, when met, will allow the species or populations to be removed from the List; and (3) estimates of the time and funding required to achieve the plan's goals and intermediate steps. Section 4 of the ESA and regulations (50 CFR Part 424) promulgated to implement listing provisions, also set forth the procedures for reclassifying and delisting species on the Federal List. A species can be delisted if the Secretary determines that the species no longer meets the endangered or threatened status based upon the five factors listed in section 4(a)(1) of the ESA that are considered when a species is added to the List. These factors are:

Listing Factor A - the present or threatened destruction, modification, or curtailment of its habitat or range;
Listing Factor B - overutilization for commercial, recreational, scientific, or educational purposes;
Listing Factor C - disease or predation;
Listing Factor D - the inadequacy of existing regulatory mechanisms; and
Listing Factor E - other natural or manmade factors affecting its continued existence.

Further, a species may be delisted, according to 50 CFR Part 424.11(d), if the scientific and commercial data available substantiate that the species or population is neither endangered nor threatened for one of the following reasons: (1) extinction; (2) recovery; or (3) original data for classification of the species were in error.

Reasons for listing – The Service listed the Barton Springs salamander as a Federally endangered species based on the following threats: (1) degradation of the quality and (2) degradation of the quantity of water that feeds Barton Springs resulting from urban expansion (listing factor A), (3) modification of the salamander's surface habitat (listing factor A), (4) lack of a comprehensive plan to protect Barton Springs watershed from increasing threats to water quality and water quantity (listing factor D), and (5) the salamander's extreme vulnerability to environmental degradation because of its restricted range in an entirely aquatic environment (listing factor E).

Because a species is added to and removed from the List based on one or more of the five listing factors outlined above, these factors should also be addressed in a listed species' recovery plan. Table 1 cross-references (1) the listing factors that formed the basis for the Barton Springs salamander's addition to the List, (2) the threats associated with each listing factor, (3) the recovery criteria that will address the threats, and (4) the numbered recovery actions (from the Recovery Program Outline, Narrative of Recovery Actions, and Implementation Schedule) that address each threat.

Table 1 - Summary of the Barton Springs salamander listing factors and threats, the recovery actions intended to address those threats, and recovery criteria for measuring recovery success.

Listing Factor	**Threat** (Section 1.6)	**Recovery Criteria** (Section 2.2)	**Recovery Actions** (Sections 2.3, 2.4, and 4.0)
A	water quality degradation	1,2,5,6	1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5, 1.2.1, 1.2.2, 1.2.3.1,1.2.3.2, 1.2.3.3, 1.2.4.1, 1.2.4.2, 1.2.4.3, 1.2.4.4, 1.2.4.5, 1.2.5, 1.2.6, 1.2.7, 4.1.1, 4.2, 4.3, 4.4, 5.1, 5.2, 5.3, 6.2, 7.1
	water quantity degradation	3,5,6	2.1.1, 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6, 2.1.7, 2.2.1, 2.2.2, 4.1.1, 4.1.4, 5.1, 5.2, 5.3, 6.1, 7.1
	surface habitat modification	5,6	3.1, 3.2, 3.3, 3.4, 4.1.1, 6.1, 7.1
D	lack of a comprehensive plan to protect Barton Springs watershed from increasing threats to water quality	1	1.2.1, 1.2.4.1, 4.1.1, 7.1
	lack of a comprehensive plan to protect Barton Springs watershed from increasing threats to water quantity	3	2.2.1, 4.1.1, 4.1.4, 7.1
E	restricted range in an entirely aquatic environment makes the salamander extremely vulnerable to decreasing water quality	1,2,4,5,6	4.1.1, 4.1.2, 4.1.3, 4.1.5, 4.1.6, 5.1, 5.2, 5.3
	restricted range in an entirely aquatic environment makes the salamander extremely vulnerable to decreasing water quantity	3,4,6	4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5, 4.1.6, 5.1, 5.2, 5.3

1.2 Description and Taxonomy

The Barton Springs salamander (Figure 1) is a member of the Family Plethodontidae (lungless salamanders). Texas species within the genus *Eurycea* inhabit springs, spring-runs, and water-bearing karst formations of the Edwards Aquifer (Chippindale 1993). They are aquatic and neotenic, meaning they retain larval, gill-breathing morphology throughout their lives. These salamanders, including the Barton Springs salamander, do not metamorphose and leave water, but become sexually mature, breed, and live in water.

The Barton Springs salamander was first collected from Barton Springs in 1946 (Brown 1950, Texas Natural History Collection specimens 6317-6321) and formally described in 1993 by Chippindale et al. Adults reach about 2.5 to 3 inches (63-76 mm) in total length and have reduced eyes and elongate, spindly limbs indicative of a semi-subterranean lifestyle. The head is relatively broad and deep in lateral view, and the snout appears somewhat truncate when viewed from above. On either side of the base of the head is a set of three, feathery, bright red gills. The coloration on the salamanders' upper body varies from light to dark brown, purple, reddish brown, yellowish cream or orange. The characteristic mottled salt-and-pepper color pattern on the upper body surface is due to the presence of melanophores (cells containing brown or black pigments, that is, melanin) and silvery-white iridiophores in the skin. The arrangement of these pigment cells is highly variable and can be widely dispersed in some Barton Springs salamanders, yielding an overall pale appearance. In other salamanders the melanophores may be so dense that individuals have a dark brown appearance. The ventral side (underside) of the body is cream-colored and often translucent so that some internal organs, and developing eggs in females, are readily visible. The tail is relatively short with a well-developed dorsal (upper) fin and poorly developed ventral (lower) fin. The upper and lower mid-lines of the tail usually exhibit some degree of orange-yellow pigmentation. Juveniles closely resemble adults (Chippindale et al. 1993). Newly hatched larvae are about 0.5 inches (12 mm) total length and may lack fully developed limbs or pigment (Chamberlain and O'Donnell 2003).

Sympatric species – The Barton Springs salamander is sympatric with (that is, occurs in the same range as) the Austin blind salamander (*Eurycea waterlooensis*), which was described by Hillis et al. in 2001. This species is closely related to the Texas blind salamander (*Eurycea rathbuni*), found in the southern portion of the Edwards Aquifer in San Marcos, Texas (Hillis et al. 2001). Like Barton Springs, San Marcos Springs also has two sympatric species of salamanders, the subterranean Texas blind salamander and the San Marcos salamander (*Eurycea nana*), which is found near the spring outlets in Spring Lake. The Barton Springs salamander is more closely related to the San Marcos salamander than either the Austin blind or Texas blind salamanders.

Morphological characteristics that distinguish the Austin blind salamander from the Barton Springs salamander include eyespots covered by skin instead of image-forming lenses, an extended snout, fewer costal grooves, and pale to dark lavender coloration (Hillis et al. 2001). In June 2001, the Austin blind salamander was designated a candidate for classification as endangered (Service 2002).

1.3 Population Status and Distribution

The Barton Springs salamander has been found only at the four spring outlets that make up Barton Springs (Figure 2) and has one of the smallest geographical ranges of any vertebrate species in North America (Chippindale et al. 1993, Conant and Collins 1998). Barton Springs, located in Zilker Park near downtown Austin, Texas (Figures 2 and 3), is an aquifer-fed system consisting of four hydrologically connected springs: (1) the Main Springs (also known as Parthenia Springs or Barton Springs Pool); (2) Eliza Springs (also known as the Elks Pit); (3) Sunken Garden Springs (also known as Old Mill or Walsh Springs); and (4) Upper Barton Springs (Pipkin and Frech 1993). Collective flow from this group of springs represents the fourth largest spring system in Texas (Brune 1981). The salamander was first observed in Barton Springs Pool and Eliza Springs in the 1940s, Sunken Garden Springs in 1993 (Chippindale et al. 1993), and the intermittent Upper Barton Springs in 1997 (City of Austin 1998b).

The extent of the Barton Springs salamander's range within the Barton Springs segment of the Edwards Aquifer (Aquifer) (Figures 4 and 5), and thus the degree of subsurface connection among these spring populations, is unknown. Sweet (1978) suggested the species was troglobitic (cave-adapted) and that the salamanders observed from the surface were discharged from the springs. However, City of Austin biologists have observed Barton Springs salamanders swimming directly into the spring outlets, including Main Springs in Barton Springs Pool (Dee Ann Chamberlain and Lisa O'Donnell, City of Austin, pers. comm. 2004). Chippindale et al. (1993) characterized the species as a predominately surface-dwelling salamander capable of living underground. Since salamander larvae are found year-round but very few eggs (which are bright and very visible) have been observed in the wild (Chamberlain and O'Donnell 2003), reproduction is believed to occur in the Aquifer.

The City of Austin initiated salamander surveys in Barton Springs Pool in 1993, in Sunken Garden Springs and Eliza Springs in 1995, and in Upper Barton Springs in 1997. Salamanders in Barton Springs Pool are found primarily in the immediate area of the spring outlets. They have also been found in the "beach" area but are rarely in the deep end of the pool, which is often covered in sediment, or in the shallow end (Figure 2). The survey area has gradually shifted from transects that included the beach and the deep end, to the immediate area around the spring outlets where salamanders appear to be most abundant. Monthly surveys conducted since 1993 have resulted in number of salamander observations ranging from 1 to 100 (City of Austin 1998b, City of Austin 1993-2003, unpublished data).

"Dozens or hundreds" of individuals were reported at Eliza Springs during the 1970s (J.R. Reddell, referenced in Chippindale et al. 1993). University of Texas at Austin biologists found very few individuals (0 to 2) during surveys conducted from 1987 through 1992 (Chippindale et al. 1993). City of Austin scuba and snorkel surveys from 1995 to March 2003 have documented an average of 12 salamanders per month with a peak in 1997 (59 salamanders) and steady decline thereafter. Following efforts to improve habitat conditions in late 2002 and 2003 (see Section 1.7, Conservation Measures), observed numbers increased to 233 in January 2004.

Salamanders have been found in the bottom of Sunken Garden Springs, its spring run, and the confluence of the spring run and Barton Creek. Total numbers of salamanders observed at Sunken Garden Springs have ranged from 0 to 85 (City of Austin and Service 1996-2003, unpublished data). While the numbers appear to be related to flow patterns, the fluctuations cannot be explained solely by flow. Other factors also likely play a role in the changes in the number of salamanders observed. For example, a decrease in salamander numbers observed during the winter of 2002-2003 appeared to be related to the presence of non-native predatory fish (Mexican tetras) (Chamberlain and O'Donnell 2003).

In April 1997, City of Austin and Service staff discovered 14 adult salamanders at Upper Barton Springs, which flows intermittently. Salamander numbers observed since that time have ranged from 0 to 14 at this site (City of Austin 1998b, City of Austin 1997-2004, unpublished data). Since salamanders are absent when this spring is dry, survey numbers are dependent on surface flow. However, there have been surveys during which no salamanders were found even though the spring was flowing (Chamberlain and O'Donnell 2003). Other factors such as salamander behavior, the occurrence of gas bubble trauma, and water quality degradation may also be important.

Various searches have failed to document Barton Springs salamanders at other Barton Springs Edwards Aquifer springs including Cold Springs, Campbell's Hole, and Backdoor Springs, all located along Barton Creek. Searches of springs in the nearby Bear Creek watershed in the early 1990s did not reveal salamanders (Chippindale 1993). However, a Service biologist reported finding a *Eurycea* salamander at a spring in the Bear Creek watershed in 2002 (Matthew Lechner, Service, pers. comm. 2002). To date, no salamanders from this site have been collected for identification.

Austin Blind Salamander – Because the Austin blind salamander was only recently described (Hillis et al. 2001), City of Austin survey counts did not distinguish between the two species until July 1998. The numbers of salamander observations fluctuate at each of the sites at Barton Springs. These fluctuations may be correlated with factors such as springflow; frequency of floods; dissolved gas levels; abundance of cover, food, and predators; sedimentation; and water quality (Chamberlain and O'Donnell 2003). The Austin blind salamander is rarely seen on the surface, and typically only small juveniles are found (Hillis et al. 2001, Chamberlain and O'Donnell 2003). They are most abundant in Sunken Garden Springs and are rarely found in Eliza Springs and Barton Springs Pool. No Austin blind salamanders have been found at Upper Barton Springs (Hillis et al. 2001, City of Austin 1997-2003, unpublished data).

1.4 Habitat

Hydrology - The four springs (Main, Eliza, Sunken Garden, and Upper Barton) and associated subterranean areas of the Barton Springs system (Figure 2) provide the only known habitat for the Barton Springs salamander. Water passing into, and through, Barton Springs comes from the Barton Springs segment of the Edwards Aquifer and, occasionally, from Barton Creek[1]. The Edwards Aquifer is a karst aquifer, characterized by subsurface features such as caves, faults, fractures, sinkholes, sinking streams (streams that lose water to the underground Aquifer), springs, and other conduits. Three segments of the Edwards Aquifer collectively supply water to at least eleven counties in central and southern Texas. These segments are separated by hydrologic divides and are commonly referred to as the southern (San Antonio) segment, the Barton Springs segment, and the northern segment (Figure 4).

The Barton Springs segment of the Edwards Aquifer (Figure 5) is located in southern Travis and northern Hays counties and provides water for municipal, industrial, agricultural, and domestic uses for over 50,000 people (Barton Springs/Edwards Aquifer Conservation District 2002). The approximate boundaries are the saline water interface to the east (with freshwater in the Aquifer and saline water to the east); the Colorado River, which divides the Barton Springs segment from the northern segment; a groundwater divide that, to a large degree, separates the Barton Springs segment from the San Antonio segment and occurs between the Onion Creek and Blanco River watersheds; and a geologic divide between the contiguous Edwards limestone overlying the Aquifer and the Glen Rose limestone to the west (Slade et al. 1985, 1986).

The Barton Springs segment of the Edwards Aquifer covers about 155 square miles and consists of two zones, the recharge zone and artesian zone (Figure 6). The recharge zone covers about 90 square miles. Recharge is the process by which water enters the Aquifer. Recharge occurs primarily as direct infiltration of runoff crossing the outcrop of the

Edwards Aquifer, where porous Edwards limestone is exposed at the ground surface. Water enters the Aquifer in one of three ways: (1) direct infiltration through the soils; (2) direct infiltration through upland recharge features (caves, sinkholes, faults, fractures, and other open cavities); or, (3) through recharge features in creeks that cross the recharge zone. Direct infiltration of rainfall through the soils and into the Aquifer makes up a small portion of the total water within the Aquifer. Much of the rainfall stays in the soil and is used by plants, is retained in shallow, subsurface water tables, or evaporates before it reaches the soil.

Runoff from the watersheds of the six creeks that cross the recharge zone provides most of the recharge (approximately 85 percent) to the Barton Springs segment of the Aquifer (Slade et al. 1985, Barrett and Charbeneau 1996). These creeks include (from north to south) Barton, Williamson, Slaughter, Bear, Little Bear, and Onion creeks (Figures 6 and 7). Creek bottom recharge features of the recharge zone can infiltrate only a limited flow of water during a storm event; therefore, if the recharge features meet their flow capacities, the remaining water leaves the recharge zone as runoff. Because the six major creeks that flow over the recharge zone contribute a substantial amount of recharge to the Aquifer, protection and conservation of surface water in these creeks is important to maintaining water quality at Barton Springs.

The remaining 15 percent of recharge occurs in the upland areas between and in smaller tributaries of the six main creeks in the recharge zone (Slade et al. 1985). However, due to efficient internal drainage within large sinkhole basins and the timing of recharge during and shortly after rain events (when the evapotranspiration rate is relatively low), the recharge contribution of the upland area may be underestimated by existing gross water balances. Consequently, the protection of the quantity and quality of flow in the upland areas between the major creek channels and in the smaller tributaries of major creeks also may be important.

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[1] When Barton Creek floods, some of the surface flow enters the pool, but during normal flow the water (continued on next page)

The artesian zone lies downstream from (east of) the recharge zone. Impermeable layers of clay cover this portion of the Aquifer, and thus water is confined under pressure and no recharge occurs. A third area, known as the contributing zone, is not part of the Edwards Aquifer but contributes water to it (Figure 6). The contributing zone encompasses the watersheds of the upstream portions of the six major creeks that cross the recharge zone (Figure 7), and therefore provides the source for most of the water that will enter the Aquifer as recharge. The contributing zone spans about 264 square miles and includes portions of Travis, Hays, and Blanco counties. The recharge and contributing zones (hereafter referred to collectively as the "Barton Springs watershed") make up the total area that provides water to the Aquifer, which equals about 354 square miles (Slade et al. 1986).

Runoff flowing across the recharge zone and entering the Aquifer reaches the water table quickly, as illustrated by comparing surface water levels at many streamflow stations with ground-water levels. Well water levels typically begin rising within one hour after water levels begin to rise in the creeks. Water levels change quickly within the Aquifer. Water levels throughout the Aquifer are highly interrelated and correlate with discharges of Barton Springs. Because much of the water moving through the Aquifer is pressurized in the dissolution cavities that transport the water, portions of the recharge zone exhibit characteristics of an artesian system.

After entering the Aquifer through faults and fractures, surface water intersects groundwater flow paths and moves through the Aquifer via caverns and other features of varying size. Groundwater movement in the western part of the Barton Springs segment is generally to the east and north. Water movement into the eastern part of the Aquifer is to the northeast, towards Barton Springs (Figure 8).

Groundwater-tracing studies conducted from 1996 to 2002 delineated some groundwater flow paths and measured groundwater velocities. Three separate groundwater basins,

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from Barton Creek enters the bypass channel near the main pool and does not enter the pool itself.

Manchaca, Sunset Valley, and Cold Springs, were mapped within the Barton Springs segment (BS/EACD 2003b, Figure 8). Each basin has at least one prominent preferred groundwater flow path, along which groundwater flow converges. The horizontal movement of groundwater flow the fastest along these preferred groundwater flow paths, from about 5 miles per day under moderate to high groundwater flow conditions to about 1 mile per day under low-groundwater flow conditions. A dye-tracer injected in a cave on Onion Creek in 2002 flowed 18 miles and reached Barton Springs within 3 days. This research emphasizes the importance of the quality and quantity of water in each of the six major creeks to Barton Spring's ecosystem and Aquifer resources.

Groundwater in the Barton Springs segment leaves the Aquifer as spring discharge at Barton Springs. This discharge is dependent on the water level in the Aquifer. Under low flow conditions in the Aquifer, surface flow ceases in Barton Creek immediately upstream of the Main Springs and many of the spring outlets become dry for extended periods. During the record drought of the 1950s, flow at Barton Springs was reduced to a record daily low of 10 cfs (cubic feet per second) (Brune 1981). This represented an 80 percent reduction from the long term daily mean flow of 54 cfs (USGS 2002). During the drought of 1995 and 1996, both Eliza and Sunken Garden Springs ceased to flow when the water level in Barton Springs Pool was lowered for routine maintenance; therefore, it is likely that the spring sites within Barton Springs are hydrologically connected.

Surface Habitat – "Surface" habitat refers to the spring pools and spring runs where the Barton Springs salamander is observed, as opposed to its subsurface, or aquifer, habitat. The Barton Springs salamander inhabits relatively stable aquatic environmental conditions. These conditions consist of perennially flowing spring water that tends to be clear, clean, mostly neutral (pH about 7), and stenothermal (narrow temperature range) with an annual average temperature of 21 to 22°C (City of Austin 1997a). Relatively constant, cool temperatures and clean, flowing spring water are essential to maintaining the well-oxygenated water necessary for salamander respiration and survival. Dissolved oxygen concentrations average about 6 mg/L (City of Austin 2001) and are directly related to springflow. Higher concentrations occur during periods of high spring discharge (City of Austin 1997a).

In addition to stenothermic, flowing water, Barton Springs salamanders appear to prefer clean, loose substrate for cover. Salamanders are found primarily under boulder, cobble, and gravel substrates, but may also be found in aquatic plants, leaf litter, and woody debris (Sweet 1978, 1984; Hillis and Chippindale 1992; Chippindale et al. 1993). City of Austin biologists frequently find Barton Springs salamanders in aquatic moss (*Amblystegium riparium*) that grows on bare rocks and the walls in Barton Springs Pool, Eliza Springs, and Sunken Garden Springs (Chamberlain and O'Donnell 2003). Moss and other aquatic plants provide cover and harbor a variety and abundance of the aquatic invertebrates that salamanders eat. Historical records indicate a diversity of plants once resided in Barton Springs Pool, including arrowhead (*Sagittaria platyphylla*), water primrose (*Ludwigia repens, L. palustris*), wild celery (*Vallisneria americana*), cabomba (*Cabomba caroliniana*), water stargrass (*Heteranthera sp*.), southern naiad (*Najas guadalupensis*), and pondweed (*Potamogeton sp.*) (Alan Plummer Associates, Inc. 2000). City of Austin biologists are working to restore the diversity and abundance of plant communities to promote the health of the Barton Springs ecosystem (see Conservation Measures, Section 1.7).

1.5 Life History and Ecology

Diet – Barton Springs salamanders appear to be opportunistic predators of small, live invertebrates. Chippindale et al. (1993) found amphipod remains in the stomachs of wild-caught salamanders. The gastro-intestinal tracts of 18 adult and juvenile Barton Springs salamanders and fecal pellets from 11 adult salamanders collected from Eliza Springs, Barton Springs Pool, and Sunken Garden Springs contained ostracods, copepods, chironomids, snails, amphipods, mayfly larvae, leeches, and adult riffle beetles. The most common organisms found in these samples were ostracods, amphipods, and chironomids (City of Austin, unpublished data).

Respiration – Barton Springs salamanders do not have lungs, but breathe through their gills and skin. Primary respiration in neotenic salamanders is through the gills; however, a substantial amount of gas exchange occurs through the skin (Boutilier et al. 1992, Hillman and Withers 1979). They also require water moving across their gills and bodies for respiration. Norris et al. (1963) found that, for three Edwards Aquifer *Eurycea* species closely related to the Barton Springs salamander, metabolic rates and oxygen consumption are highest in juveniles and decrease with increasing body size. For salamander eggs, gas exchange and waste elimination occur through semipermeable membranes that surround the salamander embryo. Oxygenation of eggs is critical to embryonic development (Duellman and Treub 1986).

Reproduction – Gravid females, eggs, and larvae have been found throughout the year in the wild, suggesting year-round reproduction. Information gleaned from captive-raised Barton Springs salamanders indicates that females can develop eggs within 11 to 17 months from hatching. One male also exhibited courtship behavior (tail undulation) at one year from hatching; all were about 2 inches (51 mm) total length (Chamberlain and O’Donnell 2003). In the wild, females with eggs are typically at least 1.6 inches (40 mm) total length (Chamberlain and O’Donnell 2003, unpublished data).

Observations of courtship among captive pairs of Barton Springs salamanders (Chamberlain and O'Donnell 2003) are consistent with Arnold's (1977) description of the tail-straddling walk, a behavior unique to plethodontid salamanders. At some point during courtship, the male deposits a spermatophore (sperm packet attached to a glycoprotein base), which is picked up by the female (Arnold 1977). Females store the spermatophore in a specialized portion of the cloaca, known as the spermatheca. Females of some species of salamanders are known to store spermatophores for up to 2.5 years before ovulation and fertilization occur (Duellman and Treub 1986). Females of some species may also store more than one spermatophore from one or different males (Houck et al. 1985a, 1985b). In 2001, a captive Barton Springs salamander female laid viable eggs one month after being isolated, indicating that females can store sperm for at least this length of time (Chamberlain and O'Donnell 2003). In most salamanders, fertilization is internal and occurs during egg-laying, when sperm are released onto eggs as they pass through the female's cloaca (Sever 2000).

Like most amphibian eggs (Duellman and Treub 1986), the salamander egg consists of an ovum surrounded by a series of concentric capsules. Barton Springs salamander ova are white and generally encompassed by three capsules (Chamberlain and O'Donnell 2003). Occasionally, an egg will contain two viable egg yolks, each of which will develop and hatch (Lynn Ables, Dallas Aquarium, pers. comm.; Chamberlain and O'Donnell 2002).

Egg-laying events have been reported from each of the institutions that have attempted captive breeding efforts, including the City of Austin, San Antonio Zoo, U.S. Geological Survey (USGS) Environmental and Contaminants Research Center, and Dallas Aquarium. Eggs are laid singly and receive no parental care. Laying a single egg occurs in minutes, and the entire egg-laying event takes hours, depending on clutch size (Chamberlain and O'Donnell 2003). Clutch sizes in the City of Austin's captive breeding program have ranged from 5 to 39, with an average of 22 eggs for 32 clutches (Chamberlain and O'Donnell 2003, City of Austin 2004, unpublished data). Of the 34 egg-laying events at the Dallas Aquarium, clutch size ranged from 10 to 55 (Lynn Ables, Dallas Aquarium, pers. comm., 2000). Females may lay all or only a few of their eggs, and most reabsorb their eggs within a few weeks after egg-laying (Chamberlain and O'Donnell 2003).

Since the City of Austin began surveying salamanders in 1993, only five eggs have been found in the wild. The first egg was found detached near a spring orifice in Sunken Gardens Springs in May 2002. The diameter of the outer egg capsule was about 0.3 inches (7 mm), and the embryo was about 0.1 inches (3 mm) in diameter. The egg later hatched in captivity. The other three eggs were found near spring orifices in Barton Springs Pool (December 2002, May and August 2003) (Dee Ann Chamberlain, City of Austin, pers. comm., 2003). Embryos begin to develop some pigmentation during the later stages of development (Chamberlain and O'Donnell 2003).

Hatching in captivity has occurred within 16 to 39 days from the time the egg is laid (Chamberlain and O'Donnell 2003). Hatching success in captive Barton Springs salamanders is highly variable and has ranged from 0 to 100 percent within and among the captive breeding locations (Dwyer et al. 1997; Lynn Ables, Dallas Aquarium, pers. comm., 2000; George Stettner, San Antonio Zoo, pers. comm., 2002; Dee Ann Chamberlain and Lisa O'Donnell, City of Austin, pers. comm., 2003). Egg mortality has been attributed to fungus (Lynn Ables, Dallas Aquarium, pers. comm., 2000; George Stettner, San Antonio Zoo, pers. comm., 2002; Dee Ann Chamberlain and Lisa O'Donnell, City of Austin, pers.comm., 2003), hydra (small invertebrates with stinging tentacles) (Lynn Ables, Dallas Aquarium, pers. comm., 2000), and other possible factors such as infertility.

Newly hatched larvae have a yolk sac, and feeding by larvae has been observed 11 and 15 days after hatching (Lynn Ables, Dallas Aquarium, pers. comm., 1999). City of Austin biologists have generally found the first three months following hatching to be a critical period for juvenile survival (Chamberlain and O'Donnell 2003).

Although reproduction has occurred in captivity, it has been sporadic and no patterns have been discerned. Eggs have been laid in tanks that simulate spring upwellings as well as in 20-gallon, closed system aquariums. At times, females have held eggs for over a year before the eggs are either laid or reabsorbed. City of Austin biologists believe stable environmental conditions, water quality, adequate space, habitat heterogeneity, and food availability may influence egg laying (Chamberlain and O'Donnell 2003; pers. comm., 2004). Providing substrates that have a rough surface (that is, not smooth, as in glass) may facilitate successful spermatophore deposition and transfer (Wright 2000). To successfully propagate the species over the long term, critical factors that induce reproduction in captivity need to be identified.

<u>Longevity</u> - As of January 2004, the City of Austin had two Barton Springs salamanders (one male, one female) that were collected as adults in June 1996, and the Dallas Aquarium had a few salamanders that were collected as adults in the spring of 1995 (Chamberlain and O'Donnell 2003). Assuming adults were at least one year old when collected, known longevity for Barton Springs salamanders in captivity is at least 10 years. Longevity in the wild is unknown.

<u>Diseases</u> - Other than gas bubble trauma, which has not been attributed to a pathogen (see Threats, Section 1.6), few physiological anomalies have been reported in the wild. An adult Barton Springs salamander collected from Barton Springs Pool in February 2001 was found to be infected with immature trematodes (*Clinostomum sp.*) located in external and internal lumps near its vent (Chamberlain and O'Donnell 2002). In January 2001, a gravid salamander was collected with an extra toe on one foot that might also have been the result of a trematode infection. Since these trematodes have life cycles that require at least two intermediate hosts, there is apparently no transmission between individual amphibians (Chamberlain and O'Donnell 2002).

The City of Austin has identified several pathogens that have affected salamanders in captivity, including fungi, an unknown myxosporidian parasite, and *Aeronomas* and *Pseudonomas* bacteria (Chamberlain and O'Donnell 2003, unpublished data). It is not known if these pathogens are present in the spring habitats of the salamanders or what threat they may pose in the wild. However, it is important to understand how they might affect captive breeding and potential reintroduction efforts.

Predators - Predation on Barton Springs salamanders in the wild is likely minimal provided there is adequate cover to hide from predators. Most of the potential predators that are native to the Barton Springs ecosystem, including fish and crayfish (*Procambarus clarkii*), are opportunistic feeders, and attempts at predation are unlikely unless the salamanders are exposed. Predatory fish include mosquitofish (*Gambusia affiinis*), longear sunfish (*Lepomis megalotis*), and largemouth bass (*Micropterus salmoides*). Mosquitofish have been known to prey on frog and salamander larvae in areas where the fish have been introduced (Goodsell and Kats 1999, Lawler et al. 1999). Longear sunfish prey on aquatic vertebrates, and largemouth bass are opportunistic predators, but feed primarily on smaller fishes and crayfish (Moyle and Cech 1988). Mexican tetras (*Astyanax mexicanus*) are non-native fish and aggressive generalist predators that are found sporadically in Barton Creek, Upper Barton Springs Pool, and Sunken Garden Springs. Large, predatory invertebrates may also prey opportunistically on small salamanders.

1.6 Threats

WATER QUALITY

Water quality at Barton Springs is influenced by both groundwater and surface water. The Barton Springs system depends on groundwater flow from the Barton Springs segment of the Edwards Aquifer. The Aquifer is fed by six stream systems (Barton Creek, Williamson Creek, Slaughter Creek, Little Bear Creek, Bear Creek, and Onion Creek) that enter the Aquifer through recharge areas. In addition to providing groundwater to the Aquifer through a recharge area, Barton Creek periodically provides water to the surface habitat of Main Springs and Upper Barton Springs. Both of these springs lie directly in the Barton Creek floodplain and are subject to high flow of surface water in Barton Creek itself. Main Springs, however, receives surface water from Barton Creek only when floodwater in the creek overtops the pool's upstream dam during floods.

Surface runoff in the contributing and recharge zones of the Aquifer directly influences the quality of water that discharges at Barton Springs. Under normal (that is, non-flood) conditions, several water purifying processes help to maintain the quality of water entering the Aquifer and ultimately Barton Springs. Water purification processes can be physical (for example, filtration of rainwater through percolation), chemical (for example, oxidation of metals), and biological (for example, microbial decomposition of organic materials). These processes naturally occur in the soils and relatively shallow water tables overlying the Aquifer over a time span of up to several years. In some cases, natural processes may only temporarily store contaminants for later release over time. During periods of high precipitation, stormwater runoff in urban areas can enter the recharge zones of the six stream systems and rapidly transport sediment, fertilizer nutrients, and toxic contaminants (pesticides, heavy metals, petroleum hydrocarbons, etc.). These potential pollutants and contaminants can be washed off the land surface overlying the Aquifer without allowing adequate time for the processes of natural purification to occur. Hauwert et al. (1998) reported that water from Williamson Creek can travel a distance of 4.5 miles from the recharge area to the springs in less than 30 hours. Therefore, runoff water may be discharged at Barton Springs in as little as several hours to several days after it has entered the Aquifer during an event of high precipitation.

Because of the flow characteristics of recharge water contributed by the six contributing streams, principal threats to water quality in the Aquifer include (1) various changes in land use that degrade the quality of stormwater runoff and (2) release of contaminants in the recharge areas of these watersheds that potentially can be transported to Barton Springs. Surface water quality can vary substantially for watersheds that have different land uses. The City of Austin (1998a) and USGS (Veenhuis and Slade 1990) have both reported that mean concentrations for most water quality constituents such as total suspended solids and other pollutants are lower in undeveloped watersheds than those for urban watersheds. Impervious cover, the composition and health of the plant community, disturbed surface areas, point source contamination (that is, a stationary location or fixed facility from which pollutants are discharged), and operating stormwater treatment facilities can all alter the quality of runoff entering the Aquifer. Where few natural buffers on the surface are present and the groundwater can move rapidly from the source area to Barton Springs, there may be limited opportunity for natural improvement of water quality to take place.

An analysis of spring discharge data by the City of Austin (2000) has indicated that degradation has occurred in a number of water quality parameters at Barton Springs over the years (Appendix A). Dissolved oxygen has decreased while conductivity, sulfates, turbidity, nitrate-nitrogen, and total organic carbon have increased. As shown in Appendix A, the percent changes in the constituents range from an increase of three percent for specific conductance to an increase of 127 percent for total organic carbon. The magnitude of these changes in water quality at Barton Springs has been variable and is dependent on flow conditions (City of Austin 2000). These changes in water quality at Barton Springs may be related to cumulative impacts of urbanization including increased groundwater use. Variations in the quality of discharge at Barton Springs may also be related to seasonal changes in the amount of precipitation (City of Austin 1997a). The extent to which these water quality changes have affected the Barton Springs salamander or its habitat is unknown. More research is needed to determine the levels of water quality degradation that will result in lethal and sublethal effects to the salamander.

Physical and Chemical Parameters of Water Quality Potentially Affecting the Barton Springs Salamander

Dissolved oxygen – Dissolved oxygen is critical for development of eggs, young, and adults; predator avoidance; feeding; reproduction; and basic survival processes in amphibians (Hillman and Withers 1979). Analysis of data by the City of Austin (2000) has indicated that dissolved oxygen at Barton Springs has been declining for a number of years. The median concentration of dissolved oxygen in Barton Springs (normalized to 50 cfs baseflow without recharge) decreased from 6.8 mg/L to 5.7 mg/L (16 percent) between 1975 and 2000 (City of Austin 2000). Dissolved oxygen levels at the springs have dropped to as low as 2.4 mg/L (City of Austin, unpublished data, 1996).

Conductivity – Conductivity is a measure of the electrical conductivity in water and is used to approximate salinity in terrestrial and aquatic environments. Water salinity reflects the concentration of dissolved inorganic solids (that is, salts such as chlorides or sulfates) in water that can affect the internal water balance in aquatic organisms. High conductivity has been associated with detrimental effects on aquatic salamanders. In a test for effects of “bad water” line well water on San Marcos salamanders (*Eurycea nana*), test individuals had 100 percent mortality within 24 hours under non-aerated conditions with a conductivity of 1145 μS/cm and a dissolved oxygen level of 6.8 to 7.6 mg/L (Edwards Aquifer Research and Data Center in City of Austin 2001). In comparison, maximum conductivity levels have been measured periodically above 1000 μS/cm at Barton Springs (City of Austin 1997a).

Conductivity may be influenced by urban runoff and other anthropogenic (man-caused) factors. At Barton Springs, average conductivity has increased since 1975 during all flow conditions. The greatest change has occurred during baseflow with recharge from 590 to 646 µS/cm which is a 14 percent increase. In contrast, the median concentration estimate for conductivity in baseflow from urban springs located in the Jollyville Plateau region increased by 4 percent from 655 to 677 µS/cm. Thus, the increase in conductivity at Barton Springs could indicate a greater urban signature in the spring water (City of Austin 2000).

Supersaturation and Gas Bubble Trauma - A recently discovered pathological condition affecting Barton Springs salamanders may be related to water quality. Between January 28, 2002 and June 26, 2002, 17 Barton Springs salamanders were found at Upper Barton Springs and 2 at Sunken Garden Springs with bubbles of gas occurring throughout their bodies. Three similarly affected salamanders also were found at Upper Barton Springs in February and March 2003 (Dee Ann Chamberlain, City of Austin, pers. comm. 2003). Of the 19 salamanders affected in 2002, 12 were found dead or died shortly after they were found. Both adult and juvenile salamanders have been affected.

The incidence of gas bubbles in salamanders at Barton Springs is consistent with a disorder known as gas bubble disease or gas bubble trauma (Bouck 1980; Crunkilton et al. 1980; Finckeisen et al. 1980; Montgomery and Becker 1980; Colt et al. 1984a, 1984b; Krise 1993; Krise and Smith 1993; Fidler and Miller 1994; Mayeaux 1994). In gas bubble trauma, bubbles below the surface of the body and inside the cardiovascular system produce lesions and necrotic tissue that can lead to secondary infections (Fidler and Miller 1994). Death from gas bubble trauma is apparently related to an accumulation of internal bubbles in the cardiovascular system (Fidler and Miller 1994). Pathology reports on affected animals at Barton Springs found that the symptoms were consistent with gas bubble trauma and that no other problems such as pathogens were indicated (Chamberlain and O'Donnell 2003). Although no Austin blind salamanders have been found with this condition, gas bubble trauma was suspected in several other species at Barton Springs including Mexican tetras (*Astyanax mexicanus*), mosquito fish (*Gambusia affinis*), Rio Grande leopard frog (*Rana berlandieri*) tadpoles, crayfish (*Procambrus clarki*), and beetle larva (Hydrophilidae) (Chamberlain and O'Donnell 2003). All of these species had problems with buoyancy, and individuals of the two fish species had bulging eyes. The symptoms of buoyancy problems and bulging eyes in these species are also consistent with gas bubble trauma.

Gas bubble trauma is caused by supersaturated water that has dissolved atmospheric gases (nitrogen, oxygen, carbon dioxide, and trace gases) in concentrations above 100 percent (Bouck 1980; Crunkilton et al. 1980; Finckeisen et al. 1980; Montgomery and Becker 1980; Nebeker et al. 1980; Colt et al. 1984a, Colt et al. 1984b; Krise and Smith 1993; Krise 1993; Fidler and Miller 1994; Mayeaux 1994). Anthropogenic factors that can lead to supersaturation include waterfall discharge from hydroelectric dams, warm water discharges from cooling facilities, algal blooms, and air or gas injection by pressurized pumps. Supersaturated groundwater in aquifers, wells, and springs may be the result of high pressures and/or increases in temperature as the water surfaces (Fidler and Miller 1994).

During the time of the salamander events in 2002 and 2003, supersaturation percentages were high (that is, above a range of 110 to 115 percent) at all four of the springs during the period in which affected salamanders were found. Upper Barton Spring had the highest supersaturation with up to 125 percent in 2002 and up to 131 percent in 2003. A well that is used to monitor water quality along the aquifer flowpath to Upper Barton Springs had over 160 percent supersaturation when tested on April 16, 2002. Water chemistry data such as pH, dissolved oxygen, temperature, and specific conductance (City of Austin 2002, unpublished data) do not conclusively indicate denitrification or other anthropogenic causes of supersaturation at the springs. Although baseline data of total dissolved gases is not available for the Barton Springs watershed in general, Upper Barton Springs has always been known for its constant bubbling (that is, degassing) which would indicate that this spring is normally supersaturated whenever it is flowing. However, there has been no evidence of gas bubble trauma in any of the aquatic organisms at this site prior to the incidents in 2002 and 2003. The City of Austin, USGS, U.S. Environmental Protection Agency (EPA), TCEQ, and Service are currently investigating this phenomenon.

Potentially, contaminants could play a role in gas bubble trauma by affecting an organism's tolerance to supersaturation. Studies of atrazine (Allran and Karasov 2001) and fuel oil (McGrath and Alexander 1979) indicate that these compounds can affect respiration and gas exchange in tadpoles. A study of elevated nitrate and nitrite levels under supersaturation showed sublethal effects that included disequilibrium and bent tails in tadpoles and a larval salamander (Marco et al. 1999). Of the four springs of Barton Springs, Upper Barton Springs may have the greatest potential for contaminant interaction with supersaturation. Triazine herbicides (for example, atrazine and simazine), PAHs, solvents, and elevated levels of nitrate have been found in water and sediment samples from Upper Barton Springs (City of Austin, USGS 2002, unpublished data). As indicated by groundwater tracing, Upper Barton Springs has a greater proportion of aquifer water from urban area sources than the other three spring sites (Hauwert et al. 2003, BS/EACD 2003). In addition, nitrate nitrogen in Upper Barton Springs is generally 1 mg/L higher than the other three spring outlets (Chamberlain and O'Donnell 2003, unpublished data). The potential for synergistic effects occurring between contaminants and supersaturated water on salamanders should be evaluated.

Pollutants and Contaminants Potentially Affecting the Barton Springs Salamander

Pollutants and contaminants occurring within the Barton Springs watershed can potentially affect the salamander and its habitat. Toxic effects to aquatic organisms from contaminants may be either lethal or sublethal and may include morphological and developmental aberrations, lowered reproductive and survival rates, and changes in behavior and certain biochemical processes (Rand et al. 1995). Each type of contaminant (for example, petroleum hydrocarbons, heavy metals, and pesticides) can have different effects on aquatic ecosystems (Hoffman et al. 1995). The Barton Springs salamander may be especially vulnerable to contaminants due to the salamander's semipermeable skin and reproductive processes. Although only limited data are available on the vulnerability of the Barton Springs salamander to toxic effects from contaminants, much is known about the effects of various compounds on many other aquatic species. Research has shown that amphibians (particularly eggs and larvae) are sensitive to many contaminants including heavy metals, pesticides, nitrites, salts, and petroleum hydrocarbons (Harfenist et al. 1989). Some crustaceans (particularly amphipods) on which these salamanders feed are especially sensitive to contaminants in water (Mayer and Ellersieck 1986, Burton and Ingersoll 1994, Phipps et al. 1995).

Sediments – Sediments are mixtures of silt, sand, clay, and organic debris that occur within water bodies either as (1) deposited sediment layers or (2) suspended sediments. Sediment derived from soil erosion has been cited by Menzer and Nelson (1980) as the greatest single source of pollution of surface waters by volume. Sediments can act as a sink for contaminants as well as serve as a transport mechanism (Menzer and Nelson 1980). Due to high organic carbon content, sediments eroded from contaminated soil surfaces can concentrate and transport contaminants (Mahler and Lynch 1999). Contaminant compounds such as polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, and pesticides may be absorbed onto sediment particles in concentrations that are orders of magnitude greater than their concentrations in the water column (Mahler and Lynch 1999).

Sediment may impact aquatic organisms in a number of ways. Excessive deposition of sediment can physically reduce the amount of available habitat and protective cover for aquatic organisms. Sediments suspended in water can smother or clog gill structures in aquatic organisms thereby affecting respiratory processes (Garton 1977, Werner 1983, Schueler 1987). Suspended sediments in highly turbid waters may impair the ability of these organisms to (1) avoid predators or (2) locate food resources and potential mates (EPA 1986, Schueler 1987). The levels of sediment contaminants also can be toxic to aquatic organisms (Menzer and Nelson 1980, Landrum and Robbins 1990, Medine and McCutcheon 1989).

Sediments taken into karst aquifers by surface runoff play a fundamental role in determining aquifer water quality (Mahler et al. 1999). Sediment flowing through karst aquifers can be a vector for contaminant transport (Ford and Williams 1994). In comparison to nonkarstic aquifer systems, karst aquifers are more vulnerable to the effects of pollution due to (1) thin surface soils overlying a karst aquifer, (2) high groundwater flow velocities, and (3) relatively short residence times that water is inside the aquifer system (Ford and Williams 1994). Sediment build-up in source areas may also block recharge water that could otherwise enter into sinkholes, caves, and other recharge features (EPA 1986, Schueler 1987).

The highly fractured limestone bedrock found in recharge areas of the Barton Springs watershed allows rapid transportation of sediments to the springs as well as movement of water. Of the four spring outlets associated with Barton Springs, Main Springs is the most studied spring for sediment discharge. Sediments are generally discharged from Main Springs after a rainfall of approximately 1.5 inches or greater within its watershed. The total amount of sediment discharged from Main Springs in a 24-hour period following a 2-inch rainfall event is approximately one metric ton (Mahler and Lynch 1999).

The Barton Springs salamander and its prey species are directly exposed to sediment-borne contaminants discharging through the four spring outlets. Trace metals such as arsenic, cadmium, copper, lead, nickel, and zinc were found in sediments of Barton Springs in the early 1990s (City of Austin 1997a). Adverse effects to the salamander and its prey from such contaminants may occur when criteria for sediment contaminants are exceeded. Criteria for evaluating the quality of sediment contaminants as suggested by the Texas Commission on Environmental Quality (TCEQ) (formerly the Texas Natural Resource Conservation Commission (TNRCC)) (TNRCC 2000), MacDonald et al. (2000), and EPA (1997) have been exceeded in approximately one-half of samples taken from salamander habitat (City of Austin 1995-2001, unpublished data). Sediment samples taken in creeks supplying water to habitat of the Barton Springs salamander have also exceeded these criteria at various times.

In addition to the threat to the salamander and its prey species from sediment-borne contaminants, sediments may also contribute to possible habitat degradation for the salamander (especially egg-laying areas). Prior to the early 1990s, Barton Springs (including Main, Eliza, and Sunken Garden Springs) had abundant coarse gravel, cobble, and plants with little sediment accumulation (David Hillis, University of Texas, pers. comm. 2002). In recent years, areas of high quality salamander habitat with clean cobble and healthy aquatic macrophytes have decreased due to deposition of sediment (City of Austin 1998b). A two to six inch accumulation of sediment typically covers available habitat at Sunken Garden Springs and Upper Barton Springs (City of Austin 1998b, City of Austin 2001, unpublished data). Although the exact origin of sediment discharging from the spring outlets is unknown, a significant proportion of the sediment discharging from the Main Springs originates from surface runoff (Mahler and Lynch 1999).

An excess of sediments and sediment-borne contaminants may have contributed to declines in salamander populations in the past. The lowest recorded observed counts of the salamander (ranging from one to six individuals) at Main Springs, occurred over a five-month period following an October 1994 flood. During the flood, Barton Creek overtopped the dam that ordinarily diverts stream flow away from the Barton Springs Municipal Pool and Main Springs. The flood deposited a large amount of silt and debris over salamander habitat in the pool, and the area occupied by the salamander during the following months was reduced to relatively small, silt-free areas immediately adjacent to the spring outlets (City of Austin 1998b). In addition, sediments collected from Barton Creek and the municipal pool following the flood were contaminated with polycyclic aromatic hydrocarbons (PAHs) at concentrations known to be toxic to an amphipod prey species (*Hyalella azteca*) of the Barton Springs salamander (Ingersoll et al. 1996, City of Austin 1998b).

Nutrients – Sources of nutrients in water include human and animal wastes, industrial pollutants, and fertilizers used on croplands, lawns, and golf courses. Excessive nutrient levels typically cause algal blooms that ultimately die back and cause progressive decreases in dissolved oxygen concentration in the water (Lampert and Sommer 1997, Wetzl 2001). Low levels of dissolved oxygen can affect salamanders and other amphibians by reducing respiratory efficiency, metabolic energy, reproductive rate, and ultimately survival (Norris et al. 1963, Hillman and Withers 1979, Pianka 1987, Boutilier et al. 1992).

Analyses of historical water quality data (pre-1978) suggest that nutrient levels have increased in Barton Springs thereby possibly reflecting degradation of water quality (City of Austin 2000). These data, however, may also reflect differences in the way nutrient data were collected in the past. Therefore, comparison of trends in nutrient levels should be qualified according to the standards used to determine nutrient levels. Nutrient-induced algal blooms periodically occur upstream from salamander habitat in Barton Creek and may be an indicator of water quality problems such as wastewater discharge or fertilizer runoff. Elevated nutrient levels within the Barton Springs watershed have been attributed to the presence of golf courses (City of Austin 1997, City of Austin, unpublished data, 2000-2002). Golf courses are often irrigated with effluents (treated municipal sewage) which can pose a particular water quality risk when existing containment (for example, retention ponds) is insufficient to contain effluents during storm events. In addition to effluent irrigation, overfertilization of golf courses may contribute to pollution of surface water and groundwater at Barton Springs.

Heavy Metals - Heavy metals are metallic elements that have an atomic weight greater than sodium (atomic wt. = 22).[2] The heavy metals group includes potentially toxic metals such as arsenic, copper, lead, and mercury. Concentrations of heavy metals in water reflect both background levels in soils and bedrock of a particular watershed as well as inputs from anthropogenic sources. Sources of heavy metals in stormwater runoff include operational wearing of vehicles, paint flaking, metal corrosion, and the leaching of wood preservatives, paving materials, and deicing salts. Increases in heavy metals associated with construction on land may occur in stormwater runoff unless adequate controls are implemented. Heavy metals can impact an organism's survival, growth, reproduction, development, behavior, and metabolism (Eisler 1988, Pain 1995). Adverse effects from heavy metals are more commonly found in early life stages or individuals that have relatively long exposures (Eisler 1988, Pain 1995). Synergistic and additive effects may also occur when heavy metals are mixed with other toxic chemicals (Eisler 1988).

Heavy metals have been detected in sediments and in the water column at Barton Springs. Relatively high levels of lead have been detected at Sunken Garden Springs (Hauwert and Vickers 1994). At current concentrations, heavy metals in sediment at Barton Springs may be toxic to salamander prey species. Several heavy metals detected in the four spring systems of Barton Springs (arsenic, cadmium, copper, mercury, nickel, and silver) exceed threshold effect levels (TELs) in sediment for a salamander prey species, the amphipod *Hyallela azteca* (Ingersoll et al. 1996). A TEL for sediment has adverse effects for at least 15 percent of sediment-associated species (benthic species).

<u>Pesticides</u> – Sources of pesticides in urban areas include lawns, road rights-of way, managed turf areas such as golf courses, parks, and ball fields. A considerable number of pesticides occur in urban streams and lakes as a result of runoff (CWP 2003). Some pesticides commonly applied in urban areas such as lawns and golf courses tend to degrade rapidly in the environment, but certain pesticides can remain biologically active for extended periods (Eisler 1986, Hill 1995). Pesticide residue concentrations found in surface water in urban watersheds reflect pesticide use associated with residential, commercial, and industrial land uses. These contaminants could impact salamander populations through contact with or ingestion of contaminated water, sediments, or food items (Hill 1995). Pathways for exposure of salamanders to pesticides include a semipermeable skin, development of eggs and larvae in water, and bioaccumulation of pesticide in the food chain. Pesticides also may affect the quality and quantity of amphibian prey and habitat (Bishop and Pettit 1992).

Several studies have found morphological and developmental aberrations and changes in biochemical processes in amphibians such as *Ambystoma barbouri* (Rohr et al. 2003),

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[2] The atomic weight of an element is the average proportionate weight of all isotopes of that particular (continued on next page)

Rana pipens (Allran and Karasov 2000, Christin et al. 2003, Gendron et al. 2003, Hayes et al. 2003), *Rana catesbiana* (Goulet et al. 2003), *Rana ridibunda* (Papaefthimiou et al. 2003), and *Xenopus laevis* (Goulet and Hontela 2003, Hayes et al. 2003, Sullivan and Spence 2003) continuously exposed to a variety of concentrations of atrazine (0.1 µg/l to 400 µg/l). Atrazine (up to 0.56 µg/l) as well as trace amounts of diazinon, carbaryl, and simazine, have been detected in spring discharge water in salamander habitat after a stormwater runoff event (USGS 2002). The extent to which the Barton Springs salamander its habitat, and prey base may be affected by varying levels of pesticides is unknown and should be evaluated.

<u>Petroleum Hydrocarbons and PAHs</u> - Petroleum and petroleum byproducts can affect living organisms adversely by causing direct toxic action, altering water chemistry, reducing light, decreasing food availability, and smothering habitat (Albers 2003). Petroleum hydrocarbons may enter water supplies through sewage effluents, urban and highway runoff, and chronic leakage or acute spills of petroleum and petroleum products (Eisler 1987, Hauwert and Vickers 1994, Albers 2003). Polycyclic aromatic hyrdocarbons (PAHs) are chemically related to petroleum hydrocarbons and are the byproducts of combustion (for example, vehicular combustion). PAH exposure can cause impaired reproduction, reduced growth and development, and tumors or cancer in species of amphibians and reptiles (Albers 2003). PAHs are also known to cause lethality, reduced survival, altered physiological function, inhibited reproduction, and changes in species populations and community composition of freshwater invertebrates (Albers 2003).

Petroleum hydrocarbons have been detected periodically in the Aquifer and at Barton Springs. Petroleum hydrocarbons, gasoline, and a visible free-phase petroleum product combined with concentrations of benzene, xylene, toluene, methyl tertiary butyl-ether (MTBE), and phenols have all been detected at various concentrations in several sampling events (BS/EACD 1994, 1998; Hauwert and Vickers 1994).

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element in comparison to the carbon 12 isotope.

Although PAHs have been detected at mostly low concentrations from 25 sites sampled on Barton Creek (City of Austin 1998a), sediment data from Barton Creek has shown high concentrations of PAHs at two sites above Barton Springs Municipal pool (City of Austin 1997a). In particular, concentrations of PAHs measured in sediment lying within drainage ways that flow into Barton Creek above Barton Springs Pool have been measured at concentrations greater than those expected to impact aquatic life (MacDonald 2000). Staff biologists from the City of Austin have identified a possible source of this PAH contamination in the Barton Springs watershed (and possibly throughout the City of Austin). This research indicates that coal tar sealants used on paved surfaces can be eroded during runoff events and thereby contribute PAH-bearing particles to nearby drainages and waterbodies. These pavement sealants are the byproduct of coal tar wastestreams in industry. The sealants are commonly used to maintain parking lots in the Austin area and are typically reapplied every three years or so. Although normally confined to the bottom of Barton Creek just above the upper dam of the municipal pool, the coal tar PAHs have the potential to be intermingled with PAHs from other sources within the Barton Creek watershed during high flood stages. As a result, sediment-borne PAHs could be deposited in salamander habitat in the aftermath of flooding and adversely affect the Barton Springs salamander.

Factors Influencing Concentrations of Pollutants and Contaminants at Barton Springs

Impervious Cover and Stormwater Runoff – Arnold and Gibbons (1996) defined impervious cover as "any material that prevents the infiltration of water into the soil." Types of impervious cover include roads, rooftops, sidewalks, patios, paved parking lots, and compacted soil. As areas are cleared of natural vegetation and the topsoil is replaced with impervious cover, rainfall no longer percolates through the ground in areas with impervious cover but is instead rapidly converted to surface runoff. The effects of impervious cover involve both the (1) construction phase of development and (2) the operation and maintenance of developed acreage. Increases in impervious cover beyond 10 percent may cause measurable water quality degradation, loss of sensitive aquatic organisms, reduction in stream biodiversity, stream warming, and channel instability within a watershed (Schueler 1994). Impairment of stream water quality can be prevented if watershed imperviousness does not exceed 15 percent in general, and watershed imperviousness should not exceed 10 percent for more sensitive stream ecosystems (Klein 1979).

Research has shown a relationship between the ecological health of stream systems and the percentage of impervious cover (Klein 1979, Griffin et al. 1980, Schueler 1987, Todd 1989, Veenhuis and Slade 1990, Booth and Reinfelt 1993, Schueler 1994, LCRA 2002). Several studies have shown relationships between the amount of impervious cover and adverse biological effects including lower diversity, impaired growth, and reduced reproduction of aquatic organisms. These impacts have been documented in both macroinvertebrates (animals with no backbone that are visible without magnification) and fish (Klein 1979, Garie and McIntosh 1986, Pedersen and Perkins 1986, Jones and Clark 1987, Hogg and Norris 1991, Masterson and Bannerman 1994, Weaver and Gagman 1994, Horner et al. 1997, May 1998).

High levels of impervious cover generally increase surface runoff volume in streams (Klein 1979, Schueler 1994, Arnold and Gibbons 1996). The increased amount and velocity of runoff caused by impervious cover can produce greater stream channel erosion and destabilization of streambanks (Klein 1979, Schueler 1994, Arnold and Gibbons 1996, CWP 2003). A cycle of bank destabilization and active erosion is initiated when stream channels adjust to high flow volumes by expanding their cross-sectional area either by (1) increasing the width of the stream or (2) cutting into the stream bed (Schueler 1994, CWP 2003). Relatively low levels of impervious cover (that is, 10 to 20 percent) have been shown to enlarge channels and cause sediment transport (Klein 1979, Schueler 1994, Arnold and Gibbons 1996, CWP 2003). Salamander habitat could therefore be affected by the greater sediment transport caused by higher surface runoff as a result of increased impervious cover overlying the aquifer.

Impervious cover is a major source of water pollutants in stormwater runoff in urban areas (City of Austin 1990, CWP 2003). These pollutants include:

1. Sediment from construction activities and streambank erosion
2. Suspended solids
3. Nutrients
4. Hydrocarbons and metal compounds from vehicles and machinery
5. Household paints and solvents
6. Trash and debris
7. Fertilizers
8. Pesticides

A nationwide analysis of 173 urban test watersheds found that impervious cover was one of the most significant variables in predicting nutrient loading by storm events (Driver and Lystrom 1986). Impervious cover increases nutrient loading in urban runoff by rapidly transporting nutrients to streams and other waterbodies (Horne and Goldman 1994). Grizzard et al. (1977) and Griffin et al. (1980) studied 16 urban watersheds and found that nutrients and heavy metals in these watersheds were relative to the percentage of impervious cover in individual watersheds. Best management practices (BMPs) are often used in urban areas to offset water quality impacts caused by stormwater runoff. However, several factors affect the effectiveness of these control mechanisms with respect to removing pollutants from runoff (see the section on "Best Management Practices" in this document); and it is not fully understood how effective these practices are at maintaining water quality on a watershed level.

Higher percentages of impervious cover in a watershed may also change aquifer water quality by increasing the amount of surface runoff water with respect to baseflow in streams. Baseflow is defined as streamflow that originates from shallow, subsurface groundwater sources in the absence of other inputs such as surface runoff. In general, baseflow from aquifer springs is relatively uncontaminated due to the filtration of rainwater as it percolates through the soil overlying the aquifer. During rainfall events, streamflow shifts from high quality baseflow water to stormwater runoff which normally carries pollutants and contaminants into stream systems (Barrett and Charbeneau 1996, Klein 1979, Schueler 1994, CWP 2003). Since recharge to an aquifer is determined largely by the quantity of baseflow in the contributing streams, impervious cover may cause a reduction in the water quality of recharge water as the shift from baseflow to stormwater runoff occurs. This water quality degradation could be reflected in aquifer springflows into salamander habitat.

A number of studies conducted in Austin, Texas and on the Barton Springs segment of the Edwards Aquifer have documented relationships between impervious cover and non-point pollution source loading. Non-point pollution sources originate from flow distributed over the land surface, as opposed to being discharged from a single, known location. A land use impact study (EHA 1984) showed that pollution loadings of nutrients, biological oxygen demand (BOD), metals, and bacteria from non-point sources were found to be positively related to average impervious cover percentages (ranging from six percent to 34 percent). In two Austin watersheds dominated by single-family housing, total phosphorus and chemical oxygen demand were found to be significantly higher in the watershed with the higher impervious cover and population density (EPA 1983). The City of Austin (1984) found that impervious cover was correlated with nutrients, BOD, and bacteria annual loadings. Another study in Austin (City of Austin 1988) found similar relationships for five large watersheds and five small suburban watersheds. Soeur (1995) determined that stormwater pollution loadings were correlated with development intensity in Austin.

Development-related changes in median concentrations for water quality constituents can be determined from data derived from water quality databases of the City of Austin by Veenhuis and Slade (1990) (Appendix B). The data represent several thousand water quality analyses for dozens of water quality constituents in 18 stream sampling sites in Austin. The watersheds surrounding the sites range in impervious cover from less than one percent to 42 percent. The data for each water quality constituent in Appendix B are provided by flow category for each sampling site (rising stages of storms and falling stages of storms). The appendix shows that substantial degradation occurs in each constituent sampled from stormwater runoff from all impervious cover ranges except for dissolved solids. For most water quality constituents, the median concentrations for storm samples are increased by about 200 to 300 percent or more from watersheds containing less than 1 percent impervious cover to watersheds containing two to seven percent impervious cover. Therefore, considerable water quality degradation could occur by the time a watershed reaches ten percent impervious cover.

Construction Activities - Soil disturbed during construction activities is easily eroded and carried away by runoff from a storm event unless best management practices are followed and structural water quality control mechanisms are properly maintained. The City of Austin (1995) estimated that construction-related sediment and in-channel erosion accounted for approximately 80 percent of the average annual sediment load in the Barton Springs watershed. In addition, the City of Austin (1995, 1997a) estimated that total suspended sediment loads have increased 270 percent over pre-development loadings within the Barton Springs segment of the Edwards Aquifer. Williamson Creek has the highest density of development of any stream in the Barton Springs watershed and also has the highest loadings per unit area for total suspended sediment and total nitrogen (City of Austin 1995).

Wastewater Discharge - Threats from domestic wastewater include fecal bacterial pathogens, nutrient-induced algal blooms, oxygen reducing organic materials, and toxic contaminants such as heavy metals and pharmaceuticals. The primary sources of wastewater discharge to the environment that may affect the recovery of the salamander are septic tank fields, sewage collection systems, and disposal of treated wastewater by irrigation. Limitations for wastewater treatment systems in the recharge and contributing zones of the Aquifer include:

1. Inadequate depth of soil
2. Effluent loading limitations in clay soils with little infiltrative capacity
3. Excessive anaerobic soil conditions due to low porosity and high soil saturation,
4. Limited biological treatment due to low organic matter content soils
5. Channelization of effluent through either lateral bedding planes or through

karst formations

6. Thin or no topsoil for treatment processes on land and pollutant attenuation
7. A potential for rapid runoff from sites with steep slopes (EHA 1985).

About 5,900 septic tanks exist within the Barton Springs watershed (Barrett and Charbeneau 1996) and can be a potential source of nitrogen and bacterial pathogens to the Aquifer. In the Lake Travis watershed, a study of on-site systems determined a considerable discharge of nitrates to shallow subsurface wells (EHA 1985). For the majority of the recharge and contributing zones, soil and geologic conditions are marginally suitable for conventional septic systems with drain field disposal. Although alternative treatment and disposal systems are being developed to overcome many of these limitations, there are no enforcement systems in place in the contributing and recharge zones to ensure facilities are operating properly (City of Austin 1996).

Threats from disposal of treated domestic wastewater by irrigation are primarily related to overloading soil treatment processes. Excess of treated wastewater by irrigation can cause poor assimilation and discharge of pollutants through subsurface pathways and surface runoff. Many irrigation tracts are managed for golf courses or other recreational uses. This results in heavier applications of fertilizers and pesticides that can be infiltrated through the soil into the groundwater or carried off by surface water discharge.

<u>Transportation Infrastructure</u> - Highways and other roadways can have major impacts on local groundwater quality (TNRCC 1994, Barrett et al. 1995). The Capital Area Metropolitan Planning Organization's Transportation Plan (2000) states that "...roadways may affect adjacent water resources with trash, oil and grease, and accidental spills of transported materials." Transportation-related impervious cover often has a greater hydrological impact than rooftop-related impervious cover (Schueler 1994). Transportation systems (highways, roads, parking lots, driveways, etc.) often are connected directly to the stormwater drainage system.

The impacts to water sources from transportation can be either hydrologic (that is, related to changes in the amount of runoff) or related to water quality. Problems associated with transportation systems have previously been discussed by McKenzie and Irwin (1983), Dupuis and Kobriger (1985), and Dorman et al. (1988). Particulates and sediment in runoff generated by transportation systems can cause problems in receiving waters by:

1. Decreasing flow capacity in drainages
2. Reducing storage volume in ponds, lakes and aquifers
3. Smothering benthic (bottom-dwelling) organisms
4. Decreasing water quality and clarity
5. Interference with the respiration of aquatic organisms

In particular, toxic materials generated by transportation systems often are transported as suspended solids. These toxins include metals, hydrocarbons, chlorinated pesticides, and PCBs, which can present acute and chronic threats to aquatic organisms.

In addition to pollutants associated with highway use, maintenance activities can also contribute toxic materials to nearby waters. Maintenance activities on bridges such as bridge cleaning present a special threat because of proximity to receiving water. Bridge cleaning can result in cleaning solutions and contaminants entering underlying or nearby surface waters. Vegetation control along roadways typically involves a combination of mechanical methods and application of herbicide, which can result in excess chemicals occurring either as residues in surface runoff or as leachates within the soil that can percolate into the underlying Aquifer.

TCEQ lists highways and roads as the fifth most common potential source of groundwater contamination in the Edwards Aquifer (TNRCC 1994). Elevated concentrations of metals, Kjeldahl nitrogen, and organic compounds have been detected in groundwater near highways and their control structures. Highway construction can also cause large increases of suspended solids into receiving waters (Barrett et al. 1995). Several major highways (a segment of State Highway 45, the southern extension of Loop

1 (MO-PAC), and the Southwest Parkway) have been built in the area overlying the Barton Springs watershed over the last decade to accommodate projected population growth and traffic demands. In addition to these existing roadways, several miles of the remainder of State Highway 45 will be built in the Barton Springs watershed within the next few years (CAMPO 2004).

<u>Hazardous Materials Spills</u> - The Barton Springs watershed is at significant risk from accidental releases of hazardous materials and is particularly at risk from spillage of hazardous materials in transport (City of Austin 1995). Any hazardous materials spill within the Barton Springs watershed could have the potential to threaten the long term survival and sustainability of the Barton Springs salamander. Numerous highways and pipelines that are major transport arteries for various petroleum products and chemicals cross the watershed. A catastrophic spill might occur if a pipeline ruptured or a transport truck overturned and its contents entered the recharge areas of the watershed. Transportation accidents involving hazardous materials at bridge crossings are of particular concern since recharge zones in creek beds can transport spilled materials directly into the Aquifer. Since the four springs of the Barton Springs complex are hydrologically connected, a contaminant spill spreading into all four springs has the potential to eliminate the entire salamander species and/or its prey base within its habitat. Table 2 shows contaminant spill information compiled by the TCEQ for Hays and Travis counties for the years 1983 through 2000. The table provides an indication of the kinds of contaminants spilled and their spill frequency within each county and its watersheds.

Table 2 - Contaminant Spill Information Compiled by the Texas Commission on Environmental Quality for Travis and Hays Counties, 1983 - 2000

County	Contaminant	Number of Events
Hays	Gasoline	13
	Diesel	3
	Freon; Chlorinated solvents; Tetrachloroethene Trichlorethene (1,2) Dichloroethane; Dichlorethane; Trihalomethanes and Chlorinated Hydrocarbon	1 each
	Unknown	5
Total Number of Events for Hays County		**26**
Travis	Gasoline	55
	Benzene-Toluene-Ethylbenzene-Xylene and Total Petroleum Hydrocarbons	7
	Diesel	5
	Gasoline and Diesel	4
	Solvents	4
	Volatile Organic Compounds (VOCs)	4
	Lead	3
	Polycyclic Aromatic Hydrocarbons (PAHs) and Benzene-Toluene-Ethylbenzene-Xylene and Total Petroleum Hydrocarbons	3
	Waste Oil	2
	Chlorinated Solvents	2
	Total Petroleum Hydrocarbons and Metals	2

County	Contaminant	Number of Events
	Gasoline and Waste Oil; Gasoline and Diesel and ALCOH Fuel; Chromium and Organics and Hydrocarbons; Benzene-Toluene-Ethylbenzene-Xylene and Perchloroethylene (PCE) and Arsenic and BA; Hydrocarbons; Paint solvents and Benzene; Volatile organics and Metals; Perchloroethylene; Methylene chloride and Benzene-Toluene-Ethylbenzene-Xylene; Total Petroleum Hydrocarbons and chlorinated solvents; Total Petroleum Hydrocarbons; Metals; Polychloronated Biphenyls (PCBs) and Total Petroleum Hydrocarbons and Volatile Organic Compounds and Metals; Benzene-Toluene-Ethylbenzene-Xylene; Volatile Organic Compounds and Chlorinated solvents and Total Petroleum Hydrocarbons; Total organic carbon and Volatile Organic Compounds (chlorobenzene; 1,4 dichlorobenzene)	1 each
	Unknown	9
Total Reported Contaminant Events in Travis Co.		**116**

In addition to the spill events reported in Table 2, three major petroleum pipeline spills have occurred over the Barton Springs segment of the Aquifer. Two of these spills have occurred over the recharge zone within the last 20 years (Rose 1986). Each of the petroleum pipeline ruptures was caused by construction activities such as digging of utility line trenches. Approximately 10,000 barrels of crude oil were recovered in each of these spills. Petroleum fumes were measured in caves almost two miles from one of the spill sites, but water quality impacts of the two spills to the Aquifer and Barton Springs are not known.

Measures for Minimizing Degradation of Water Quality in the Barton Springs Watershed

Impervious Cover Limitations – Klein (1979) recommends that watershed imperviousness should generally not exceed 15 percent and that watershed imperviousness should not exceed 10 percent for sensitive stream ecosystems. Overall impervious cover in the Barton Springs watershed is approximately five percent (LCRA

2002). The level of impervious cover varies among the six major drainages within the watershed. As of 2000, the six watersheds that provide water to Barton Springs had the following impervious cover levels (LCRA 2002): (1) six percent in Barton Creek, (2) sixteen percent in Williamson Creek, (3) seven percent in Slaughter Creek, (4) five percent in Bear Creek, (5) three percent in Little Bear Creek, and (6) three percent in Onion Creek. The percentage of impervious cover within the Barton Creek watershed is likely to increase as the human population increases.[3]

Currently, no single regulatory mechanism exists to restrict increases in impervious cover throughout the Barton Springs watershed; however, there are several state regulations (such as the Edwards Rules) and municipal ordinances (such as the City of Austin's Ordinance #920903-D "Save Our Springs" and similar ordinances for the City of Dripping Springs and Village of Bee Caves) that are designed to minimize water quality degradation from new development. The Edwards Rules (30 Texas Administrative Code Chapter 213) regulate activities that may potentially pollute the Edwards Aquifer. These rules apply to all zones (recharge, transition, and contributing) of the Edwards Aquifer and were designed to ensure that:

> "the existing quality of groundwater not be degraded, consistent with the protection of public health and welfare, the propagation and protection of terrestrial and aquatic life, the protection of the environment, the operation of existing industries, and the maintenance and enhancement of the long term economic health of the state" (30 Texas Administrative Code Chapter 213).

Significant changes to the Edwards Rules were implemented in 1999 after the Barton Springs salamander was listed as endangered. These changes included a requirement for permanent BMPs that remove 80 percent of the increase in post-construction total suspended solid load to be installed in new developments over the Barton Springs watershed. Although there are no restrictions on impervious cover in the Edwards Rules,

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[3] In the year 2000, census figures showed that Hays County had 98,000 in population and Travis County had 812,000 (U.S. Census Bureau 2002). According to the Texas State Data Center (2002), projected (continued on next page)

the regulations do provide incentives to developers in the form of exemptions and exceptions from permanent BMPs for developments with less than 20 percent impervious cover.

Based on trend data that shows degradation of water quality at Barton Springs over the years (see Appendix A), existing regulations for maintaining water quality may not adequately protect the Barton Springs salamander. To date, no comprehensive study has been conducted to evaluate the effectiveness of existing state and local regulations in protecting water quality in the Barton Springs watershed. In addition, Chapter 245 of the Texas Local Government Code permits "grandfathering" of state regulations. Grandfathering allows developments to be exempted from new requirements for water quality controls and impervious cover limits providing that the developments were planned prior to the implementation of such regulations. However, these developments are still obligated to comply with regulations that were applicable at the time when project applications for development were first filed. The potential impact of the grandfathering statute as enacted by the State of Texas has not been examined with respect to existing regulations that protect water quality in the Barton Springs watershed.

<u>Buffer Zones</u> - Buffer zones are natural areas that have not been disturbed by construction, development, or any other type of disturbance that can significantly alter existing vegetation. A buffer zone can protect an aquatic ecosystem from land use impacts by providing shade, baseflow storage, streambank stability, and filtration of upland runoff (May 1998). Filtration in buffer zones is accomplished through soil buffering capacity, vegetation, and microorganisms to remove or break down pollutants (Mulamoottil et al. 1996).

The buffer size required to fully protect aquatic resources varies considerably depending on the (1) functional value of the resources, (2) intensity of adjacent land use, (3) buffer

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increases in population for Hays and Travis counties by the year 2040 will be 175 percent and 69 percent, respectively.

characteristics, and (4) specific buffer functions required (Castelle et al. 1994).[4] A review of the scientific literature on buffer size requirements indicates that minimum buffer widths of 50 to 100 feet are necessary to protect streams from degradation under most conditions (Castelle et al. 1994). In a study on the effects of buffer zones on habitat of two salamander species (*Eurycea cirrigera* and *Desmognathus fuscus*), Wilson and Dorcas (2003) found that relatively small buffer zones (for example, buffer zones that are 35, 100, or 200 feet in width for watersheds greater than 100 acres) alone do not provide adequate protection of the stream ecosystems. Relatively large buffer zones of undisturbed land may be needed throughout the entire watershed to protect sensitive, high value aquatic resources (Wilson and Dorcas 2003).

Buffer Zones for Riparian Areas - Riparian areas are lands that are adjacent to streams, rivers, and ponded areas (lakes, reservoirs, etc.). Plant communities in riparian areas are usually diverse with a high degree of structural and compositional diversity (Gregory et al. 1991). Riparian areas comprise a relatively small proportion of the landscape but are much more important to the proper hydrological and ecological functioning of ecosystems than their small size would indicate (Vannote et al. 1980, Gregory et al. 1991). The riparian area is an interface zone between terrestrial and aquatic ecosystems that plays a central role in the movement of water, air, sunlight, and nutrients through watersheds (Gregory et al. 1991). Riparian plants, in particular, moderate the effects of upland land use and play an important role in ecosystem structure and function.

Well-maintained buffer zones in riparian areas can substantially reduce impacts of urban development (May 1998). The ecological and hydrological processes associated with riparian areas can determine the overall effectiveness of buffer zones in riparian areas (Vannote et al. 1980). The extent of the riparian zone and the degree to which it can buffer the aquatic ecosystem from upland impacts depends on the size of the stream and the areal extent and composition of vegetation (Schueler 1995). The effectiveness of

[4] Types of wetland functional values include: "providing essential habitat for wildlife; water storage to prevent flooding and protect water quality; and recreational opportunities for wildlife watchers, anglers, hunters and boaters" (Wisconsin Department of Natural Resources 2002).

riparian areas for buffering streams from the impacts of forestry and agriculture has been well studied, but less work has been focused on the effects of urbanization. The impact of urban development on the functioning of riparian areas can vary widely with amount of disturbance to streamside vegetation, the land use type and intensity, and the remaining buffering capacity of the area (May 1998).

The City of Austin Ordinance #920903-D (Save Our Springs) and ordinances for the City of Dripping Springs and the Village of Bee Caves all include measures to protect riparian areas. In addition, Federal Emergency Management Agency floodplain regulations and section 404 of the Clean Water Act operate to restrict development of riparian areas along major creeks or headwater tributaries. Although mechanisms to protect riparian areas exist, buffer sizes based on site-specific characteristics need to be identified and evaluated for effectiveness.

<u>Buffer Zones for Stream Headwaters</u> - In general, many watershed regulations (including the Land Development Code for the City of Austin) recommend a correspondingly wider buffer for downstream portions of a stream network. However, recent evaluations have concluded that riparian buffers in headwater streams (generally, first or second-order systems) have a greater influence on water quality overall within a watershed than buffers set up in downstream reaches. Headwater streams are the hydrological capillaries of the watershed and serve as natural areas for water retention. Approximately 80 percent of total stream length resides in these small order streams. During periods of low rainfall, baseflow in streams is generated primarily from release of retained shallow groundwater that has filtered through headwater buffers and stream channels. Loss of headwater streams and wetland areas may result in a dramatic alteration of downstream hydrology (Poff et al. 1997).

The hydrologic interactions between groundwater and surface water in the Barton Springs watershed are the ecological basis for maintaining adequate water quality for downstream organisms such as the Barton Springs salamander. Although extreme flood events may overwhelm the mitigating impact of these headwater streams, flood flows from the more common, interval events are slowed and allowed to infiltrate into shallow groundwater through the headwater stream system.

Headwater stream buffers are also important in maintaining water quality due to the high surface area to flow volume ratio they provide. This ratio allows for longer flow retention within the soil where natural filtration processes and pollutant removal occurs. Even ephemeral headwater streams are efficient at trapping sediment and pollutants adsorbed onto the sediment, which results in less exposure to organisms downstream such as the Barton Springs salamander by increasing the probability that such pollutants will be naturally degraded in headwater buffer soils (Dieterich and Anderson 1998). During flood events, headwater streams and buffers provide the only natural moderation of peak flows and storm water velocities that are influenced by development. Depending on their size and effectiveness, headwater buffers have the ability to trap sediment from upland development if the erosion control practices during construction are not adequate. Structurally, the roots of vegetative buffers form the natural glue for small stream banks and helps prevent sediment loading caused by bank failure and erosion. This was identified in an assessment of Onion Creek which determined that root binding by mature woody species in steeper banks of small channels is critical to the overall stabilization of the entire channel system (City of Austin 2003b).

Headwater streams help to maintain the ecological diversity found downstream in a watershed. They provide temperature control through riparian vegetation shading (Horne and Goldman 1994). Vegetative cover in headwater areas also provides diversity of habitat and shelter for wildlife. Habitat connectivity created by contiguous buffer systems allows for wildlife accessibility to nursery and feeding areas that otherwise would be less available in an urbanized landscape. This is important for species that use different parts of the watershed during different portions of their life cycle.

Downstream buffers have proportionally less impact on polluted water already in the stream. Even the most beneficial buffer strips along larger streams cannot significantly improve water that has been degraded by improper buffer practices higher in the watershed. However, buffer strips along larger systems also have unique benefits, as they are typically longer and wider than those of low-order streams and have a greater potential to provide significant wildlife habitat and movement corridors (Fischer 2000). Both approaches (buffers for headwater streams and along downstream reaches) are needed to preserve the functionality of the watershed. Studies have indicated a minimum buffer width should be set at 100 feet on either side of a stream (Castelle et al. 1994, Schueler 1995), including headwater and lateral feeder streams.

Buffer Zones for Environmentally Sensitive Areas - Buffers around sensitive environmental features such as surface recharge features of the Aquifer can also contribute to water quality protection. Surface recharge features such as caves, sinkholes, faults, fractures, springs, and seeps can have direct connections to the Aquifer (City of Austin 1997a). Within the Barton Springs watershed, approximately 15 percent of the recharge to the Aquifer is derived through surface features with the remaining recharge (85 percent) occurring within streams that cross this zone (Slade et al. 1986). Unless buffer zones are installed, pollutants in surface runoff may enter the Aquifer through a sinkhole or other recharge feature with little or no attenuation (Field 1998).

Compact, clustered developments – Compact development (also known as open space development or low impact development) is a type of development that is characterized by (1) the preservation of large, undisturbed areas or open space across the development site and (2) limitations on the amount and distribution of impervious cover. The goal of this type of development is to reduce the impacts of development on the surrounding environment. Compact development provides an opportunity to design subdivisions in a manner that reduces impervious cover and conserves undisturbed native land as much as possible. The protection of open spaces can produce benefits similar to those from limiting impervious cover such as decreases in stormwater runoff and pollutant transport (Arendt 1996). Increasing the amount of land preserved in its natural state may result in a reduction in the number of acres of managed landscape and turf (areas that are intensely managed through the use of irrigation, fertilization, or pest control practices) that can serve as a source of pollutants during stormwater runoff or irrigation events. A compact development that is clustered at a single site of a large area may also reduce the need for longer roads. In addition, a clustered design can be beneficial in protecting the surrounding watershed by reducing the amount of construction activities that lead to increased erosion and sediment transport.

Best Management Practices – Best Management Practices (BMPs) are "methods that have been determined to be the most effective, practical means of preventing or reducing pollution from non-point sources" (EPA 2002). BMPs include public information programs, street sweeping, and structural controls such as wetlands, wet ponds, dry ponds, filters, and grassy swales. In an analysis of 140 nationwide studies of individual BMPs, the Center for Watershed Protection (CWP) estimates that properly-maintained BMPs can be used to keep the water quality in watersheds to rural levels if impervious cover is less than 30 to 35 percent (CWP 2003).

There have been many studies of the effects of best management practices on the water quality of urban runoff including Welborn and Veenhuis (1987), Barrett et al. (1998), and Glick et al. (1998). Based on these studies, a summary of the general removal efficiencies for different types of BMPs is presented in Table 3 below.

Table 3 – Removal Efficiencies for BMPs

BMP Type	Removal Efficiency
Public information program	5-10 percent for most water quality constituents
Wetlands	up to 90 percent (best for nutrients, some metals may actually increase)
Wet ponds	60-80 percent (best for sediment-related constituents)
Dry ponds	30-70 percent (best for sediment-related constituents)
Filters	30-70 percent (most filters are horizontal and are best for sediment-related constituents, efficiency depends on maintenance)
Grassy swales	10-20 percent (more efficient for sites with appropriate swale characteristics)

BMP Type	Removal Efficiency
Street sweeping	0-10 percent (some evidence that street sweeping can increase pollutant loading)

The wide range (30 to 70 percent) in filter efficiencies in Table 3 indicates that the efficiency of a particular filter can depend on the maintenance of the filter material. As indicated by field inspections and other evidence, the efficiency of filters may be lower than indicated in the table when the filters are not being properly maintained (Glick et al. 1998). Also, the efficiency of filters and ponds can be substantially reduced if they contain stormwater bypasses or overflows.

In an effort to mitigate the impacts of urbanization, the City of Austin and other agencies have required BMPs to be designed and implemented throughout the area. Over 1,000 BMPs currently exist in the Austin area and more are being developed. Although some grassy swales and wet ponds are being used as BMPs in the Austin area, filters are more prevalent (TNRCC 1999). Each type of BMP has a different level of effectiveness. In 1987, the USGS published a report presenting data regarding the effects of two different runoff controls (a sand filter and a grass-lined swale) on the quality of runoff in Austin for 22 storm runoff events (Welborn and Veenhuis 1987). The sand filter produced a 21 percent decrease in dissolved volatile solids and an 81 percent decrease in fecal bacteria between the inflows and outflows of a pond with a sand filter. In comparison, the study found that the grass swale had no effect on water quality. However, Barrett et al. (1998) has reported significant removal efficiencies for two other grass-lined swales associated with highways in Austin. The effectiveness of such controls possibly is dependent on the site characteristics (for example, area size, vegetation, slope, and soil type), and the type and extent of development in the basin.

The Edwards Rules (30 Texas Administrative Code 213) require the use of structural BMPs if the impervious cover of a site will exceed 20 percent impervious cover. BMPs have been implemented in the Austin area by various ordinances (for example, Save Our Springs ordinance) and other rules to provide for better treatment of runoff. Although

BMPs such as filters can remove substantial amount of pollutants as water quality constituents, they generally do not eliminate water quality degradation caused by urbanization. The effectiveness of BMPs at the watershed level for the Barton Springs watershed should be evaluated.

WATER QUANTITY

Another potential threat to the Barton Springs salamander and its ecosystem is low flow conditions in the Aquifer and at Barton Springs. The long term mean flow at the Barton Springs outlets (Barton Springs Pool, Eliza Springs, Sunken Garden Springs, and Upper Barton Springs) from 1917 to 1986 is 54 cfs. The lowest flow recorded at Barton Springs was 10 cfs during the drought of record in the 1950s (City of Austin 1998b), and the highest-recorded flow was 166 cfs. Discharge decreases as water storage in the Aquifer drops, which historically results from lack of recharging rains rather than groundwater withdrawal for public use. However, increased demand for water from the Aquifer can also reduce the quantity of water in the Barton Springs segment of the Aquifer. In 1989, the total actual pumping rate from the Barton Springs segment of the Edwards Aquifer was approximately 1.21 billion gallons/year (BS/EACD 2002, unpublished data). For 2001, actual pumping rate was approximately 2.09 billion gallons/year (BS/EACD 2002, unpublished data), which was almost double the rate in 1989. Increased groundwater pumping and its effects on Aquifer levels and springflows become more pronounced during dry periods. During drought conditions and low levels of water in the Aquifer, both Eliza and Sunken Garden Springs have ceased flowing during drawdown of Barton Springs Pool for routine pool maintenance.

The best available information suggests that reduced quantity of water in the Aquifer could threaten the survival of the Barton Springs salamander, even under climatic conditions where the species has previously survived. The lowest short-term flow measured at Barton Springs was 9.6 cfs in March 29, 1956 (USGS 1957) under drought of record conditions. Pumpage during the 1950s was estimated to be about 0.66 cfs

(Brune and Duffin 1983). Thus a conservative estimate for total discharge (pumpage and springflow) under drought conditions is 10.3 cfs. Subsequent porous media modeling by BS/EACD and Bureau of Economic Geology (Scanlon et al. 2000) also indicates that under similar drought of the 1950s climatic conditions, Barton Springs flow decreases in direct proportion to simulated pumpage levels, and Barton Springs is likely to go dry as pumpage levels reach about 10 cfs. In 2003, the BS/EACD reported that permitted and estimated exempt pumpage levels combined are approximately 10.5 cfs (BS/EACD 2003a).

Concentration of dissolved oxygen is directly related to spring discharge. Dissolved oxygen tends to be highest during periods of high recharge when large volumes of well-oxygenated surface waters enter the aquifer and lowest when recharge is minimal and spring discharge is low (City of Austin 1997a). Extended and/or frequent periods of low flow and corresponding low dissolved oxygen levels could be detrimental to the development, reproduction, and survival of the Barton Springs salamander. While the salamander survived the drought of the 1950s, the decrease in dissolved oxygen levels since 1975 (City of Austin 2000) could cause low flows to have a greater impact on the Barton Springs salamander and its survival.

Specific conductance increases under low flow conditions and thus may also reduce salamander survival by reducing the solubility of oxygen which is needed for salamander respiration. Chloride, sodium, sulfate, and magnesium also increase during low spring discharge (City of Austin 1997a) and show a marked increase when flows drop below 40 cfs (Chamberlain and O'Donnell 2003). Specific conductance at all of the spring sites has increased since 1975, and Sunken Garden Springs tend to have the highest specific conductance levels because of their proximity to the saline, "bad-water" line (City of Austin 1997a).

The water level in Eliza Springs and Sunken Garden Springs drops when the dam gates of Barton Springs Pool are opened to lower the water level, indicating a hydrologic connection among these spring sites. If the water in Barton Springs Pool is drawn down during periods of low spring discharge, the water in Eliza Springs ceases to flow, stranding and killing salamanders. To prevent Eliza Springs from going dry, the water in Barton Springs Pool is no longer drawn down when flows are less than 54 cfs (City of Austin 1998b). It is possible that under drought of record and current pumping conditions, Eliza Springs would cease flowing even if the gates of Barton Springs Pool remain closed.

Upper Barton Springs ceases flowing when the collective discharge from Barton Springs is about 40 cfs (David Johns, City of Austin, pers. comm., 2002). Sunken Garden Springs and Eliza Springs may also go dry under very low flow conditions, resulting in the loss of a substantial portion of the salamander's known range. Investigation into the genetic variation of the salamanders between the four spring sites is needed. However, if genetic variation exists, the loss of individuals from Sunken Garden Springs and Eliza Springs has the potential to decrease genetic variation among the salamander population, thereby reducing the possibility of recovery and long term persistence of the species.

Low flows would also hinder salamander "rescue" efforts in the event of an emergency (such as a catastrophic spill). Even if adequate time to respond to a spill were possible before it reached the springs, observed salamander numbers tend to decrease with springflow and thus collecting large numbers of salamanders becomes increasingly difficult as flows decline. If one or more of the spring sites were dry, salamander collection at that site would not be possible. Eliza Springs may be an especially important collection site in the event of a spill, since it has supported the highest surface abundance of salamanders and is the most accessible site.

MODIFICATION OF SURFACE HABITAT

Results from research specific to the effects of physical habitat modification on similar amphibians are limited. Habitat loss to urbanization was one factor that was referenced in the decline of the California tiger salamander (*Ambystoma californiense*) (Barry 1994). Researchers also noted that the Ouachita dusky salamander (*Desmognathus brimleyorum*) is threatened by the disruption of the hydrology of its habitat and this factor may account for the salamander's disappearance from seven historic collection sites (Crosswhite and Leslie 1998). A study conducted in Prairie Creek State Park, California, on the impacts of sediment washed into the creek after a storm event found densities of the Pacific giant salamander (*Dicamptodon tenebrosus*) and the southern torrent salamander (*Rhyacotriton variegatus*) were significantly lower in the streams that had been impacted by sediment (Welsh 1998).

The hydrology and ecology of Barton Springs Pool, Eliza Springs, and Sunken Garden Springs have been altered by impoundments built around each of these perennial springs during the early to mid-1900s. During the 1970s, a bypass was built to divert Barton Creek around Barton Springs Pool. A rock wall surrounds Sunken Garden Springs, which has a rubble substrate. Water flows from the Sunken Garden spring pool into a springrun to Barton Creek. A concrete culvert also previously drained water from Sunken Garden Springs but was capped in 2000. The culvert still discharges water into Barton Creek, indicating groundwater migration into fractures. An amphitheater was built around Eliza Springs in the early 1900s, and a concrete bottom was installed around the 1960s. Water from the aquifer flows up through seven, one-foot diameter holes in the concrete floor and 13 rectangular vents along the edges of the concrete. A culvert drains water from Eliza Springs into the Barton Creek bypass. These man-made structures limit the potential surface connections among salamander populations and other aquatic organisms. While they help retain water in the spring pools during low flows, the natural flushing of sediments and connection with the flora and fauna of Barton Creek are reduced. These physical modifications present unique management challenges that are exacerbated by declining water quality and quantity.

Several other past activities have resulted in habitat disturbance and the loss of Barton Springs salamanders. For example, impacts to the salamander and its habitat have been noted from (1) lowering of the water level in the pool, (2) use of high pressure fire hoses in areas where salamanders occur, (3) hosing sediment into their habitat, (4) diverting water from Sunken Garden Springs into Barton Creek below Barton Springs, (5) loss of native vegetation, (6) alteration of primary habitat by recreational pool users, (7) chlorinating the pool, and (8) runoff from the park train station and construction activities above Eliza Springs (City of Austin 1998b). In 1998, after the salamander was listed, the City of Austin completed a Habitat Conservation Plan (HCP) to avoid, minimize, and mitigate impacts from the operation and maintenance of Barton Springs Pool (see discussion under Section 1.7, Conservation Measures).

Pollution events in the vicinity of the pool, as well as in the watershed, can impact the salamander's habitat. In 1992, improper application of chlorine used to clean the pool resulted in a fish kill. Following this fish kill, salamanders were only found in a 50 square foot area immediately around the outflow of the Main Springs instead of throughout the more extensive habitat area of approximately 4,300 square feet where they had been located previously (Chippindale et al. 1993). The City of Austin discontinued use of chlorine after this event.

Another threat to the salamander is periodic flooding of Barton Creek into Barton Springs Pool, during which silt and debris are deposited in the pool thus reducing the amount of habitat for the salamander (City of Austin 1998b). The degree of impact in the Main Springs depends upon the intensity and duration of the flood and existing conditions in the upstream watersheds. Records of past floods indicate that flooding can result in significant damage to the main structure of the pool. During past decades, the impact of floods in the main pool has varied from minor disturbance and sediment deposition to major events that dislodged large concrete sections from the shallow end of the pool. Previous damage has also included removal of gravel from the beach area, removal of silt and plants from the main channel of the pool, and the deposition of gravel, sediment, and debris in the deep end of the pool.

Analysis of City of Austin data (June 1993 to August 1998) and other historical data indicate that the springs experience episodic events such as flooding, droughts, algae blooms, and increased levels of silt and sediment. Such episodic events, in combination with sediment and nutrient loading and past pool management activities, have resulted in the salamander habitat changes outlined above, as well as changes in the ecology of the springs and the population dynamics of its resident biota such as the introduction or removal of plant and animal species, both native and non-native.

City of Austin staff has documented changes in the ecology of the pool and adjacent springs. Some areas of the pool have become covered with silt and debris deposited by flooding in Barton Creek and sediment loading from the Aquifer. The sediment in these areas often became anoxic (devoid of oxygen) and ceased to provide suitable habitat for many of the aquatic organisms that inhabit the springs. At Eliza Springs, the build-up of silt in the bottom of the spring has reached depths in excess of one foot. The reduction in available suitable habitat for aquatic organisms is largely affecting by levels of sediment and nutrient loadings in the Aquifer, as well as the frequency and intensity of episodic natural events. Silt and sediment also clog the interstitial spaces in the gravel and cobble that serve as a prime habitat for the salamanders and their invertebrate prey. These organisms depend on the interstitial spaces for protection, habitat, and an abundant supply of well-oxygenated water.

1.7 Conservation Measures

Efforts to Protect the Barton Springs Watershed (Listing Factors A,D,E – *see Section 1.1 for an explanation of the listing factors)*

Several large-scale projects have implemented proactive actions that help protect the Barton Springs watershed. For example:

Land Acquisition and Conservation Easements - In May 1998, City of Austin voters approved $65 million in utility revenue bonds for the purchase of land and conservation easements in the Barton Springs contributing and recharge zones for the protection of the city's drinking water quality. Approximately 15,000 acres were acquired (including fee title purchases and conservation easements). Most of the Shield Ranch is included in this total, including a 6,593-acre conservation easement area with about 6.3 miles along both sides of Barton Creek in the contributing zone. In November 2000, City of Austin voters approved over $13 million for the protection of open space within the Barton Springs watershed. As a result of these two approved propositions, the City of Austin has spent over $78 million and has protected approximately 16,662 acres (Junie Plummer, City of Austin, pers. comm., 2004).

The Hill Country Conservancy (HCC) is a nonprofit land trust committed to preserving open space in the Barton Springs segment of the Edwards Aquifer. HCC works with private landowners, conservation buyers and sellers, the real estate and business communities, and numerous agencies of local, state, and Federal government to preserve land and protect water quality and quantity within the Barton Springs watershed. HCC has succeeded in conserving approximately 2,200 acres of its goal to preserve 50,000 acres in the Barton Springs watershed and is working to develop a conservation easement on the 5,685-acre Storm Ranch located in the contributing zone of the Barton Springs watershed.

Balcones Canyonlands Conservation Plan (BCCP) - The BCCP is a regional habitat conservation plan developed by the City of Austin and Travis County. The goal of the BCCP is to acquire and manage at least 30,428 acres for the protection of 8 endangered species (2 birds and 6 karst invertebrates) and 27 species of concern (City of Austin and Travis County, Texas 1996). Although the Barton Springs salamander is not a targeted species for protection within the BCCP, land acquisition in the Barton Springs watershed under the BCCP does benefit the salamander through preservation of open space, and therefore water quality, over the recharge zone.

For example, the Barton Creek macrosite of the BCCP includes two areas of preserve land. The eastern area is all in the recharge zone and includes the City of Austin's Friesenhahn tract and three tracts managed by the City of Austin's Parks and Recreation Department (PARD): (1) Barton Creek Wilderness Park (955 acres), (2) Barton Creek Ventures/Wilderness Park (44 acres), and (3) Barton Creek Greenbelt (813 acres), for a subtotal of 1,872 acres. The western area includes The Nature Conservancy of Texas' Barton Creek Habitat Preserve (4,084 acres) and the City of Austin's Senna Hills tract (35 acres) for a subtotal of 4,119 acres. The total area currently protected by the BCCP in the Barton Creek macrosite is 5,991 acres, which is 339 acres less than the acquisition target of 6,330 acres (Travis County Transportation and Natural Resources Department. 2004).

Water Quality Protection Recommendations – In September 2000, an initial set of water quality protection recommendations were developed and distributed to local jurisdictions within the Barton Springs watershed. A working group, which represented broad expertise in water quality protection technology and consisted of staff from the City of Austin, LCRA, University of Texas at Austin, and local engineering firms, developed this document in an effort to outline site-specific management actions designed to minimize water quality degradation from new development in the Barton Springs watershed.

In 2001, the Lower Colorado River Authority (LCRA) began construction on a new waterline that extended availability of treated surface water to portions of northern Hays and southwestern Travis counties. Although the project was intended to alleviate growing demands on groundwater pumping from the Edwards Aquifer, the new waterline can negatively affect the Barton Springs salamander by stimulating development over the Barton Springs watershed. Before construction on the pipeline began, the Service issued a biological opinion on the first phase of the waterline project. A biological opinion is a document issued by the Service that explains the Service's opinion as to whether or not a Federal action is likely to jeopardize the continued existence of listed species. Because the installation of the pipeline required a permit from the U.S. Army Corps of Engineers, the Service considered this project a Federal action. As part of the biological opinion, the Service and LCRA entered into a Memorandum of Understanding that contained the water quality protection recommendations to be used by developers intending to build in areas serviced by the new waterline. In addition to developments receiving water from the LCRA pipeline, these recommendations have also been used in other large developments to help minimize water quality impacts within the Barton Springs watershed.

Following the implementation of the September 2000 water quality protection recommendations, the same working group, in close coordination with Service staff, prepared and updated two, more detailed draft water quality recommendations documents in November 2002. A draft technical guidance document provided the scientific justification for the water quality recommendations and guidance on how the measures could be implemented. It also addressed the shortcomings of the September 2000 document, specifically addressing impacts from golf courses and wastewater disposal systems, and the need for monitoring. These recommendations provide scientific information and expert opinion on how water quality impacts from new developments can be minimized. However, further refinement of the November 2002 documents is needed. A regional approach such as the regional water planning process (see below) may provide the most appropriate and efficient mechanism for the refinement, further development, and establishment of recommendations and technical guidance documents for the protection of water quality within the Barton Springs watershed.

Regional Water Planning - In December 2002, Hays County and City of Austin officials launched an effort to develop a regional water plan. This effort was designed to produce ordinances or rules to be implemented by local, regulatory jurisdictions for the protection of water quality within the recharge and contributing zones of the Barton Springs segment of the Edwards Aquifer, and gain the Service's endorsement that these ordinances will provide habitat protection for the Barton Springs salamander. Those entities that would be responsible for enacting such ordinances as well as several environmental organizations, government agencies, stakeholders, and community participants are directly involved in this process, which will also focus on voluntary and cooperative regional approaches directed at achieving protection of water quality and quantity. This process may be an effective way to address water quality threats faced by the salamander if the approaches addressed in the plan are adopted by all jurisdictions throughout the Barton Springs watershed.

City of Austin and Texas Department of Transportation National Pollutant Discharge Elimination System (NPDES) Permits - The City of Austin and Texas Department of Transportation are monitoring development and traffic to provide data necessary to implement a long term program to reduce pollutant loading.

City of Austin's Action Plan to Address Top Ten Pollutant Sources – The City of Austin's Watershed Protection and Development Review Department has summarized the top pollutant sources in the Barton Springs watershed and have developed action plans that outline the steps needed to reduce pollutant loading from each source. The action plans need to be refined and the roles of potential partners need to be clarified, which could possibly occur through the regional water planning process mentioned above.

Efforts to Protect Surface Habitat (Listing Factors A,D)

As mentioned under "Modification of Surface Habitat", the City of Austin (1998b) is implementing a habitat conservation plan (HCP) to avoid, minimize, and mitigate incidental take of the Barton Springs salamander resulting from the continued operation and maintenance of Barton Springs Pool and adjacent springs. An HCP is a plan designed to offset any harmful effects a proposed project may have on an endangered species. Through the habitat conservation planning process, non-federal entities may receive an incidental take permit to conduct activities that might incidentally harm or "take" a listed species by mitigating their impacts with activities that promote species conservation. The City of Austin's HCP provides a comprehensive structure for management decisions regarding salamander habitat. The City of Austin has assumed management responsibility for the habitat and has an incidental take permit (effective until October 2013) that requires several measures to ensure that management impacts to the Barton Springs salamander are minimized.

Pool maintenance procedures are designed to provide a safe recreational facility and healthy environment for swimmers and salamanders. Major provisions of the plan include:

- Avoiding or minimizing the stranding of salamanders and other aquatic organisms by lowering the "beach" in Barton Springs Pool to keep it from going dry during drawdown for cleaning; modifying the gate system on the lower dam of Barton Springs Pool to slow the rate of drawdown and gradually lower the water level; and preventing drawdown of the pool when flows are less than 54 cfs.
- Training lifeguard and maintenance staff to protect salamander habitat and the ecology of Barton Springs Pool.
- Controlling erosion and preventing surface runoff from entering the springs.

- Ecological enhancement and restoration.
- Monthly monitoring of salamander numbers.
- Public outreach and education.
- Dedication of a portion of the pool revenues to fund conservation and research efforts for the Barton Springs salamander.
- Establishment and maintenance of a captive breeding population of Barton Springs salamanders.

In the fall of 2002, City of Austin biologists initiated concerted efforts to improve the habitat conditions in Eliza Springs (City of Austin 2003a). The drainage infrastructure has been kept clean of debris, increasing flow from this structure and allowing for more natural flushing and cleansing of the spring ecosystem. While mosquitofish and crayfish formerly dominated Eliza Springs, a combination of trapping and relocation and the improved flow regime have limited their numbers. Sediment flushing exposed a layer of gravel and cobble that had been embedded and thus unavailable as habitat for the salamanders. Several species of native aquatic plants, including water primrose (*Ludwigia* sp.), rush (*Eleocharis* sp.), and water hyssop (*Bacopa* sp.) have been successfully transplanted from upper Barton Creek into Eliza Springs. Following habitat improvements, salamander abundance began increasing in May 2003 and reached 233 in January 2004 (City of Austin 2002-2004, unpublished data).

Captive Breeding (Listing Factors A,E)

Even with the best management practices and guidelines in place, an emergency situation could develop that threatens the continued existence of the Barton Springs salamander. Hazardous material spills in the Barton Springs watershed can pose an acute threat to this isolated population. It will be necessary, therefore, to maintain captive populations of Barton Springs salamanders for possible reintroduction. A scenario could develop where it becomes necessary to collect additional animals from the wild and hold them in captivity until an emergency situation has passed. The situation could be short or long term.

Captive propagation and maintenance of the Barton Springs salamander has met with limited success, and knowledge of the requirements for captive propagation remains rudimentary. Until such requirements are better understood, captive breeding efforts run a high risk of failure. Further, salamander collection depends on continuous springflow at the spring sites. Ideally, salamander collection would occur slowly over a long period of time at all of the spring sites to maximize genetic diversity and minimize impacts on the wild populations. Large numbers would be collected only in the event of a potentially catastrophic spill, assuming adequate notification to respond before the spill reaches the springs.

The City of Austin has committed to the funding and development of a permanent captive breeding program that will serve as a long term program for the species (City of Austin 1998b; Chamberlain and O'Donnell 2002, 2003). As of December 2003, the City of Austin had over 100 Barton Springs and Austin blind salamanders and is continuing to expand (Chamberlain and O'Donnell 2003; Dee Ann Chamberlain and Lisa O'Donnell, City of Austin, pers. comm., 2004). Several salamanders are also on display at the "Splash!" exhibit at Barton Springs. There are no genetically representative captive breeding populations of the Barton Springs salamander.

The City of Austin is building a permanent captive breeding facility at their Austin Science and Nature Center, with the goal of maintaining a viable captive breeding population as specified in their HCP (City of Austin 1998b). City of Austin biologists are working with the American Zoo and Aquarium Association to develop a captive breeding plan for the Barton Springs salamander. They maintain detailed records on individual salamanders in the program using a global information network and information database (Animal Records Keeping System), which is managed by the International Species Information System. Records include collection site or parentage (if born in captivity), sex, reproductive condition, egg-laying events, hatching, growth, and mortality. These data are summarized in annual reports to the Service in accordance with their HCP (City of Austin 2002, 2003a).

Longhorn Partners Pipeline, L.P. (Longhorn) has committed to establishing a captive breeding site for the Barton Springs salamander at the San Marcos National Fish Hatchery (SMNFH, Horizon 2000). In addition to the funds identified for equipment and facility costs ($325,000), Longhorn will provide $55,000 per year for an employee salary to run the refugium, for as long as refined product (gasoline) flows through the pipeline (Tom Brandt, SMNFH, pers. comm. 2002).

Salamander Monitoring (Listing Factors A,E)

The City of Austin conducts monthly surveys for Barton Springs salamanders in Barton Springs Pool, Eliza Springs, Sunken Garden Springs, and Upper Barton Springs (see Section 1.3, Population Status and Distribution). In addition, City of Austin biologists have developed a technique to identify individual salamanders based on photographing the unique patterns of pigments on the head and body. They use this pattern recognition technique to identify individuals in the captive breeding program. The ability to recognize individuals with little or no disturbance to the salamanders is necessary to develop a capture-recapture program in the wild, which would provide better population estimates and allow individuals to be tracked over time. City of Austin biologists are implementing this technique in the field and are exploring the feasibility of other techniques (Lisa O'Donnell, City of Austin, pers. comm. 2003).

Water Quality Monitoring (Listing Factors A,D)

The City of Austin and U.S. Geological Survey regularly conduct water quality monitoring at Barton Springs. The City of Austin's water quality monitoring schedule includes:

- Continuous monitoring of pH, specific conductance, temperature, turbidity, total dissolved gas, dissolved oxygen, and depth using multiprobe data loggers in Barton Springs Pool, Eliza Springs, and Upper Barton Springs, when it is flowing (with plans to include Sunken Garden Springs contingent on funding;

- Twice weekly testing for bacteria for Barton Springs Pool;

- Biweekly analyses of nutrients, total suspended solids, and chlorophyll A for Barton Springs Pool. A companion sample collected at the downstream dam is analyzed for total suspended solids and chlorophyll A. Field parameters measured include pH, temperature, turbidity, dissolved oxygen, and specific conductance;

- Quarterly tests for nutrients, total suspended solids, major ions, and heavy metals (arsenic, copper, iron, lead, nickel, and zinc) in all four springs (when flowing). Field parameters measured include pH, temperature, turbidity, dissolved oxygen, and specific conductance;

- Semiannual analyses that include the above quarterly list of parameters in addition to a more comprehensive list of metals and organic compounds. Field parameters include pH, temperature, turbidity, dissolved oxygen, and specific conductance;

- Annual analyses at all four springs that include the above quarterly list of parameters in addition to a more comprehensive list of metals and organic compounds. Field parameters are collected that includes pH, temperature, turbidity, dissolved oxygen, and specific conductance.

Education and Outreach (Listing Factors A, D, E)

The Austin Nature and Science Center directs the "Splash!" exhibit which raises public awareness about the Edwards Aquifer. Resources at the "Splash!" exhibit include Edwards Aquifer models, exhibits illustrating the importance of healthy buffer and riparian zones, water quality monitoring, an Edwards Aquifer database and library, and aquaria displaying the aquatic life of upper and lower Barton Creek, Barton Springs, and the Colorado River.

The Austin Nature and Science Center coordinates educational activities with local school teachers and classrooms, public outreach programs, and adult educational programs such as the Master Naturalist Program. Through the efforts of the Austin Nature and Science Center, along with the support and assistance of local, state, and Federal agencies, thousands of central Texas citizens and visitors will have the opportunity to understand the importance of Barton Springs and the Edwards Aquifer and the need for protection of these unique resources.

Karst preserves are being maintained by the City of Austin, Texas Cave Management Association, neighborhood associations, and private owners to provide the opportunity for the public to experience karst ecosystems on the Edwards Aquifer. Existing preserves include the Goat Cave Karst Preserve, the Lady Bird Johnson Wildflower Center, the Village of Western Oaks Karst Preserve, Whirlpool Cave Preserve, Dick Nichols Park, and the Slaughter Creek Metro Park.

Other outreach programs coordinated by the City of Austin include: 1) Earth Camp, a field trip program for schools in the Austin Independent School District that educates children on Barton Springs, salamanders, watersheds, karts aquifers, and preservation of water quality; 2) Earth School, an in-school lesson for fifth-graders that educates students on the effects of pollution on watersheds and aquifers; 3) Hydrofiles, a program that provides creek monitoring information and data analyses to participating high school students and teachers; and 4) printed educational outreach materials intended to publicize the sensitivity of both the aquifer and the Barton Springs and Austin blind salamanders.

2.0 RECOVERY

The following section presents a strategy for recovery of the species, including objective and measurable recovery criteria and site-specific management actions to monitor and reduce or remove threats to the Barton Springs salamander, as required under section 4 of the Endangered Species Act. The Recovery Plan addresses the five statutory listing/recovery factors (section 4(a)(1) of the ESA; see Section 1.1, Introduction) to the current extent practicable to demonstrate how the recovery strategy and specific actions will ameliorate threats to the Barton Springs salamander. The recovery criteria provide benchmarks for recovery allowing the Barton Springs salamander to be downlisted to threatened status and ultimately removed from the list of threatened and endangered species.

2.1 Recovery Strategy

The ecosystem upon which the Barton Springs salamander depends must be conserved in order to meet the goal and objectives of this recovery plan. The five broad areas outlined below form the basis of the Recovery Strategy for the Barton Springs salamander. Information is still needed to fully implement some of the actions outlined below. All actions should be modified and/or adaptively managed as new information becomes available. Many of these actions should occur simultaneously to ensure recovery of the species.

Protection of Water Quality

The salamander appears to be restricted to the four spring outlets, including the pools surrounding these springs and an unknown extent within the Aquifer. Because the majority of water that leaves the Aquifer exits at Barton Springs, the salamander may be affected by impacts to water quality occurring in the Barton Springs watershed.

Avoidance and Remediation of Catastrophic Spills

A comprehensive hazardous material spill plan for the Barton Springs watershed should be developed, and measures to avoid and/or completely contain catastrophic spills need to be implemented. The catastrophic spill plan and its implementation should also include retrofitting hazardous materials traps, as necessary, and properly maintaining them to minimize the potential of a contaminant spill reaching salamander habitat. An evaluation of the effectiveness of this plan in minimizing risks to the Barton Springs salamander to low levels also is needed to determine if risks are low enough to meet recovery criteria.

Avoidance and Minimization of Chronic Water Quality Degradation

Minimizing Effects from Expanding Urbanization -- There are few point discharges of water pollution within the Barton Springs watershed. Therefore, most of the potential sources of water quality degradation come from stormwater runoff and direct infiltration of contaminants in the uplands (Barrett and Charbeneau 1996). The highest potential for stormwater degradation comes from areas that have been developed.

The Austin area is experiencing rapid population growth, resulting in increasing residential and commercial development and transportation infrastructure. Existing development has been shown to degrade the quality of water within the Barton Springs watershed (See Threats, Section 1.6). However, the majority of land within the Barton Springs watershed has not yet been developed. The water from the undeveloped land within the watershed has kept the water flowing from Barton Springs relatively clean. A primary consideration of new development within the Barton Springs watershed should be the protection of water quality.

Currently, no comprehensive plan is in place that provides guidance for development throughout the entire Barton Springs watershed. Development within certain local jurisdictions may comply with building ordinances designed to protect water quality;

however, other development located outside those jurisdictions may not be held to similar standards. The benefits gained by the developments that follow guidance designed to protect water quality may be impeded or degraded by effects from developments that are built with little or no restrictions. A regional approach that provides the same guidance to all developments throughout the Barton Springs watershed would be the most efficient method of developing and implementing mechanisms designed to protect water quality and the Barton Springs salamander. Such mechanisms should be created with a goal of preventing further degradation of the Edwards Aquifer and surface water and demonstrated by the following objectives: (1) development should not result in an increase in annual average stormwater pollutant loads over pre-development conditions for discharges from a site, (2) development should be designed, constructed, and maintained in a manner that does not alter the form, function, and hydrology of the drainage network/stream system, and (3) water quality constituents are maintained at levels that allow for the long term survival of the Barton Springs salamander in its natural environment (see Section 2.2 for further discussion).

The authority needed to prevent further water quality degradation may be most effectively adopted, implemented, and enforced by a single state entity with jurisdiction over the entire Barton Springs watershed or by each of the local jurisdictions within the watershed that agree to regulate new development under the same or similar conditions. In either case, a regional approach to addressing the components of the recovery strategy designed to protect water quality within the Barton Springs watershed may be the most effective way to protect the habitat crucial to the survival of the Barton Springs salamander. Two examples of large-scale, regional approaches that have previously taken place or are currently underway to address water quality are the development of water quality recommendations used in the construction of developments receiving water from the LCRA pipeline and the regional water planning process discussed in Section 1.7, Conservation Measures.

Based on available scientific information and expert opinion (see *Measures for Minimizing Degradation of Water Quality in the Barton Springs Watershed* in Section

1.6 for further discussion) regarding the impacts of urbanization, protecting water quality within the Barton Springs watershed from new development should involve the following components:

- Impervious cover limits – Research from the Austin area and other parts of the country consistently show a negative relationship between water quality and the percentage of impervious cover. Based on the information presented in Section 1.6, detectable degradation of stream ecosystems is known to occur by the time a watershed reaches 10 percent impervious cover. Positive effects suggest that BMPs can offset up to 5 percent of impervious cover given effective stormwater treatment, but more research is needed to determine the effectiveness of BMPs in removing effects of impervious cover (Schueler 1994). To promote the survival and recovery of the Barton Springs salamander, impervious cover should be limited throughout the Barton Springs watershed, particularly in the recharge zone, since water enters directly through the porous limestone formations and receives little or no filtration before reaching Barton Springs. Impervious cover limitations throughout the Barton Springs watershed used in concert with BMPs designed and maintained to keep water quality at pre-development levels should be an integral part of a regional plan designed to protect water quality.

- Buffer zones for streams and other sensitive environmental features (caves, sinkholes, fissures, springs) – Buffers are natural areas that remain free of disturbances that alter the existing vegetation. Riparian buffers can play an important role in water quality protection (including baseflow quality), hydrological retention, and flow regime maintenance by protecting physical aquatic habitat, quality and quantity of recharge, and streambank integrity (Schueler 1995). The combined use of impervious cover limits, buffers, and BMPs are effective tools for minimizing water quality degradation caused by new development. Based on existing literature, buffers less than 16 to 33 feet in width are known to provide little protection of aquatic resources (Castelle et al. 1994); however, larger buffers (for example, buffers greater than 100 feet in width) were found to be necessary for water quality protection and wildlife habitat functions (Johnson and Ryba 1992).

Several factors must be considered in determining an adequate buffer width and configuration, including intensity of adjacent land use, slope steepness, stream order, soil characteristics (such as depth, texture, erodibility, moisture, and pH), floodplain size and frequency of inundation, hydrology, and buffer characteristics (such as type, density, structure of vegetation, and buffer length). For example, larger buffers may be necessary when the buffer zone is in poor condition (such as sparse vegetation, disturbed and/or erodible soils); is surrounded by intense land use; or is located within watersheds with increased impervious surfaces that result in high nutrient, chemical, and sediment inputs, and runoff (such as buffers located adjacent to urban and suburban areas) (Kennedy et al. 2003).

Providing riparian buffers for headwater streams has a greater influence on overall water quality within a watershed than those buffers occurring in downstream reaches. However, the greater length and width of buffer strips along larger systems are beneficial in providing significant wildlife habitat and movement corridors (Fischer et al. 2000). Both approaches (buffers for low-order, headwater streams and along larger systems) are necessary to preserve the functionality of a watershed and should be considered during the development of a regional plan to protect water quality.

In addition to riparian buffers, other sensitive environmental features (such as caves, sinkholes, faults, fracture zones, springs, seeps, wetlands) that influence water quality should be buffered from development activities. State and local regulations generally recommend a minimum buffer zone of 150 feet around the feature (radius) provided there is adequate vegetative cover and the soils in the buffer zone are stable (that is, not eroding). This distance generally provides the vegetative cover and surface area for pollutant removal from runoff before it enters the feature. For features with drainage areas exceeding 150 feet, the minimum buffer size should be expanded.

- Compact, clustered developments – Compact development (also known as open space development) is a form of development that reduces the average lot size, limits the disturbance and expense from infrastructure sprawl, provides better protection for environmentally sensitive or historically significant features, and provides neighborhood preserves and/or parks while maintaining overall density. Benefits to water quality include the preservation of large, contiguous, undisturbed areas; protection of hydrologically sensitive areas; reductions in impervious cover; less managed landscapes (such as lawns); and stormwater detention and filtration. These benefits are achieved by clustering development density on one portion of the site in exchange for reduced density elsewhere on the site (Arendt 1996). Low impact development designs that rely primarily on vegetative and other structural approaches increase the likelihood of long term water quality protection and minimize future maintenance responsibilities. Such designs should be encouraged by local jurisdictions on a regional scale for new developments over the Barton Springs watershed.

- Structural water quality controls – The structural controls that are most effective in protecting water quality in the Barton Springs watershed should be determined. Retention irrigation systems have often been used for developments over the Barton Springs watershed as the best management practice (BMP) when the prevention of water quality degradation is the goal. However, other BMPs such as vegetative filter strips, sedimentation-sand filtration, and sedimentation basins combined in series may also accomplish this goal if appropriately engineered and maintained. Data demonstrating effectiveness in preventing water quality degradation for the Barton Springs watershed should be gathered to adequately assess the success of BMPs and BMPs in series. The use of those BMPs found to be the most effective in preventing degradation of water quality should be encouraged on a regional scale.

- Other strategies to reduce pollutant loads – Other strategies to reduce pollutant loads from new and expanding developments over the Barton Springs Watershed should be developed and implemented. These strategies may include controlling or minimizing wastewater disposal systems, erosion and sediment control, ensuring sufficient funding for inspection and maintenance of BMPs, integrated pest management, and public education. Because effluent-irrigated golf courses may cause water quality degradation, strategies that address this source of pollutant loading should also be evaluated and implemented. Examples of strategies to minimize effects of golf courses and other managed turf areas include nutrient balances, minimized turf areas, water quality controls, buffers from waterways and recharge features, and ongoing monitoring. Such strategies should be outlined during a regional planning process and implemented throughout the Barton Springs watershed.

Development of a Land Preservation Strategy – Land preservation through acquisition, conservation easements, or deed restrictions can provide permanent protection for water quality and quantity generated by the preserved tract. Preservation of undeveloped land could also be used to offset higher impervious cover for specific development projects while maintaining low impervious cover levels throughout the Barton Springs watershed. A strategy to preserve large tracts of land within the Barton Springs watershed should be developed as part of a regional approach to protect water quality within the Barton Springs watershed along with proposals for specific funding mechanisms to implement this strategy.

Reduction of Pollutant Loads from Existing Development – Because degradation of water quality at Barton Springs has been documented (City of Austin 2000), efforts should be made to reduce pollutant loads from existing development and other existing sources of pollution such as golf courses. Such reductions may be achieved through the construction of water quality ponds, commonly known as "retrofit" ponds. Limitations to this approach include the lack of open space in previously developed areas to site the ponds and the high cost of pond construction. Retrofit projects also may result in undesirable impacts or destruction of sensitive riparian or canyon areas where the ponds must be sited due to drainage patterns and topography. Structural retrofits should be considered and implemented where space is available, when it is reasonably cost-effective, and where specific water quality problems have been identified. Public outreach and educational efforts to reduce pollutant sources from existing developments (in particular from landscape practices, automotive fluids, and household wastes) are important strategies to complement structural controls.

Reduction of Pollutant Loads from Transportation Infrastructure – Retrofitting existing transportation infrastructure such as roads and bridges with water quality control structures and hazardous material traps to avoid or minimize catastrophic and/or chronic water quality degradation in the recharge and contributing zones of the Aquifer should be examined. If it is found that certain structures are potential contributors to pollutant loads or pose a significant risk of catastrophic spills, these sites should be retrofitted where possible. A plan should be developed and implemented to route hazardous cargoes away from the recharge zone and critical environmental features. All water quality control structures and hazardous material traps should be regularly monitored and maintained.

Sustain Water Quantity at Barton Springs

An overall Aquifer Management Plan to guide short-term and long term approaches for managing water quantity and groundwater use from the Edwards Aquifer should be developed and implemented to conserve this species and maintain sufficient high quality springflows. Because there are a substantial number of users dependent on the Aquifer, creation of this plan should involve representation from multiple user groups to assure equitable consideration of various human needs (social and economic) while implementing salamander recovery actions. The protection of baseflow is needed to ensure adequate flow at Barton Springs. Several of the water quality protection methods mentioned above (such as limiting impervious cover and providing riparian buffers and buffers for headwater streams) are also beneficial in protecting water quantity and should be addressed in a regional Aquifer Management Plan. Pumping limits also should be an integral part of this plan. Groundwater pumping from the Barton Springs segment of the Edwards Aquifer should be limited, particularly during drought, when pumping should be reduced such that spring flow at Barton Springs does not drop below that which would allow the long term survival of the Barton Springs salamander in its natural environment.

<u>BS/EACD Proposed Habitat Conservation Plan</u> – The Barton Springs/Edwards Aquifer Conservation District (BS/EACD) is a groundwater conservation district mandated to "...conserve, protect, and enhance the groundwater resources of the Barton Springs segment of the [Edwards] aquifer" (BS/EACD 2002). Their jurisdiction covers portions of both Travis and Hays counties. Because they track and regulate the amount of groundwater pumping from the Barton Springs segment, their involvement in developing an Aquifer Management Plan is essential. This organization is developing a regional habitat conservation plan that will identify the effects of groundwater pumping on the Barton Springs and Austin blind salamanders and will include measures to avoid, minimize, and mitigate for those impacts resulting from permitted groundwater pumping. BS/EACD staff will collaborate with experts and various agencies to develop a plan that addresses the needs of the salamanders, groundwater demands and sustainability, and

appropriate planning and aquifer management strategies that will protect the Barton Springs and Austin blind salamanders from degradation of water quantity.

Manage Local Surface Habitat

Surface habitat management at Barton Springs is another area of concern for species conservation. The City of Austin has obtained an incidental take permit for pool cleaning activities and accepted the responsibility for management of the salamanders and their habitat at Barton Springs. The Habitat Conservation Plan developed for the permit application incorporates an adaptive approach to enhance local surface habitat conditions for the Barton Springs salamander. Salamander populations at all four spring sites are monitored monthly as a condition of the City of Austin's incidental take permit. Steps should be taken to ensure continued, long term protection of the salamander.

Maintain a Captive Population for Research and Restoration Purposes

The purpose of recovery under the ESA is to reduce the threats to the species in the wild. For this reason, captive populations alone do not constitute recovery nor meet the purpose of the ESA. The establishment of captive populations should be considered a precautionary measure, and the primary focus should be placed on conservation of the ecosystem. Though the main strategy of this recovery plan is to reduce risks and conserve the species in its native ecosystem, this plan includes captive propagation as a tool to provide additional assurance that the species will be conserved for the long term.

Genetically representative captive populations should be established and carefully maintained so that suitable stock is available for reintroduction or supplementation purposes, if needed. A Captive Population and Contingency Plan should be developed that includes the following: (1) clearly identified protocols for establishing and maintaining captive populations, and (2) conditions that might make it necessary to bring large numbers of individuals in from the wild (for example, an emergency such as a large contamination spill at the springs). This plan should be developed in a manner that is consistent with the Service's *Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act* (Service 65 FR 56916-56922, 2000).

Due to the difficulties in conducting field research on a species that spends part of its time in inaccessible locations (such as areas with deep layers of large rocks), biological research on the Barton Springs salamander may be facilitated using individuals from a captive population. This would also avoid impacts on the wild population from possible effects of research.

In addition, research needed to effectively manage a captive breeding program suitable for use in restoration efforts includes the following:

- Salamander population genetics should be more fully characterized to provide information needed to design a captive propagation plan;
- Captive breeding techniques should be developed to ensure dependable captive breeding and rearing techniques for Barton Springs salamanders;
- Reintroduction techniques should be developed.

Develop and Implement Education and Outreach Programs

Conservation of this species and its ecosystem will involve the support and participation of a wide variety of people and organizations. Therefore, public information and education is an important component of this recovery strategy. The City of Austin plans to move their captive breeding facility to the Austin Nature and Science Center. This should be an effective location for disseminating information about the Barton Springs and Austin blind salamanders to the public. Other local jurisdictions, government agencies, non-profit organizations, and other groups should disseminate information directed at educating the public on endangered species issues and the importance of protecting water quality and quantity within the Barton Springs watershed. Developers can incorporate environmental educational programs into their development plans for residential, industrial, and/or commercial developments. Topics may include information about endangered aquatic species, karst geology, best management practices, buffer zone maintenance, fertilizer application, pesticide use, organic gardening, water conservation, and disposal of hazardous household chemicals. Materials used may be obtained from the Service, TCEQ, American Water Works Association, National Ground Water Association, Water Environment Federation, or from other appropriate sources. Development of kiosks, displays, video, and/or other media to present material covering a variety of non-point source pollution control topics should be encouraged. Alternative educational efforts, such as site-specific recharge feature displays and educational nature trails are also encouraged.

2.2 Goal, Objectives, and Recovery Criteria

Goal - The goal of this recovery plan is to reduce the threats and secure the conservation of the Barton Springs salamander in its native ecosystem at Barton Springs at a level whereby the species can be removed from the list of threatened and endangered species (delisted).

Objective 1 – Protect water quality (Listing Factors A, D, E - s*ee Section 1.1 for an explanation of listing factors).*

Downlisting Criterion 1A - Mechanisms (such as laws, rules, regulations, and cooperative agreements) are in place to protect water quality (including sediment quality) in the Barton Springs watershed and ensure the long term survival of self-sustaining populations of the Barton Springs salamander in its natural environment.

Additional information is required to determine the water quality needs of the Barton Springs salamander to refine this criterion. Specifically, the following actions should be conducted: (1) determine if previously documented levels of water quality constituents may be directly or indirectly detrimental to the salamander and (2) determine which water quality constituents may negatively impact the salamander, and at what levels (concentrations, durations, and combinations of these) impacts may occur. Until this criterion is refined, concentrations of water quality constituents that could have a negative impact on the salamander should remain below levels that could exert direct lethal or sublethal effects (such as effects to reproduction, growth, development, or metabolic processes) on individuals or developmental life stages, or indirect effects on the salamander's habitat or prey base. Although not all of the thresholds for each of the possible water quality constituents are known, exposure to these constituents should not exceed those exposures (that is, concentrations, durations, and combinations of these) to which the salamander has been exposed in the past.

Delisting Criterion 1A - The mechanisms to prevent water quality degradation at Barton Springs are shown to be effective.

Delisting Criterion 1B - Commitments are in place to ensure the continued, long term protection of water quality at Barton Springs.

Objective 2 – Prevent or contain catastrophic spills (Listing Factors A, E)

Downlisting Criterion 2A - A comprehensive hazardous material spills plan for the Barton Springs watershed is developed and implemented with measures to avoid or completely contain catastrophic spills.

The risk of harm to the Barton Springs salamander from hazardous spills should be reduced to an insignificant level. This criterion needs to be refined by developing a methodology for assessing risk to the Barton Springs salamander.

Delisting Criterion 2A - Evaluation of the hazardous spills plan shows it to be effective in minimizing risks to the Barton Springs salamander to an insignificant level.

Delisting Criterion 2B - Long term commitments to implement the hazardous materials spills plan are in place.

Objective 3. Protect water quantity (Listing Factors A, D, E).

Downlisting Criterion 3A – Develop and implement an Aquifer Management Plan that ensures natural springflows at Barton Springs outlets (Main Springs, Eliza Springs, Sunken Garden Springs, and Upper Barton Springs). Springflows are continuous at Main Springs, Eliza Springs, and Sunken Gardens Springs even in the most severe drought. During drought, flows do not fall below the historic low flow of 10 cfs, as measured at the USGS monitoring well that measures flow from all four sites combined.

Downlisting Criterion 3B - The Barton Springs Pool is managed in a way that springs remain flowing as described in the City of Austin's HCP (City of Austin 1998b), which means that the pool will not be lowered for cleaning should the flow fall below 54 cfs.

Delisting Criterion 3A - Measures to ensure natural springflows at the four spring outlets and continuous springflows at Main Springs, Eliza Springs, and Sunken Garden Springs are shown to be effective.

Delisting Criterion 3B - Long term commitments are in place to maintain these measures.

Objective 4 – Maintain healthy, self sustaining salamander population levels throughout the Barton Springs ecosystem (Listing Factors A, E)

Downlisting Criterion 4A - Barton Springs salamanders appear to be thriving in their natural environment, as indicated by their presence and condition based on survey information over the course of each year.

Downlisting Criterion 4B - As an indicator that reproduction is adequate to sustain a stable or increasing population, salamanders less than 1-inch total length should comprise at least 50 percent of the total number of salamanders observed each year.

Delisting Criterion 4A - Survey data indicate the Barton Springs salamander population is stable or increasing and expected (with a probability of at least 95%)

to be viable for 100 years. This determination should be based on threat assessments and salamander survey data. The data should cover an adequate time span and include appropriate demographic parameters to assess long-term viability.

Objective 5 – Manage surface habitat to adequately reduce local threats the Barton Springs ecosystem (Listing Factors A,D).

Downlisting Criterion 5A - Surface habitat management is met by the ongoing implementation and completion of the actions detailed within the City of Austin's HCP (see description pp. 1.7-5, 1.7-6).

Delisting Criterion 5A - Long term monitoring shows that the measures outlined in the HCP have been effective.

Delisting Criterion 5B – Long term commitments are in place to maintain the measures outlined in the HCP.

Objective 6 - Establish and maintain a captive population to ensure protection from extinction (Listing Factors A, E)**.**

Downlisting Criterion 6A - A Captive Propagation and Contingency Plan (CPCP) is developed and implemented.

Downlisting Criterion 6B - At least two genetically representative populations of captive Barton Springs salamanders are established in secure locations.
This criterion should be refined through further studies to determine the adequate size and genetic structure of captive populations. This information should be outlined during the development of the CPCP.

Delisting Criterion 6A – The adequate size and genetic structure of captive populations has been determined and achieved.

Delisting Criterion 6B - Captive breeding is shown to be successful and reliable.

Delisting Criterion 6C - Commitments are in place to maintain adequate captive populations for any needed salamander restoration work.

2.3 Recovery Program Outline

The actions needed to meet recovery criteria are organized below into seven categories: (1) water quality, (2) water quantity, (3) surface habitat management, (4) salamander monitoring and research, (5) captive breeding, (6) public outreach and education, and (7) post-delisting monitoring. Planning and scientific research activities will generate information that assists with management of the species. Monitoring the implementation of those management actions will ensure that management tools are appropriately and effectively addressing impacts on the species. If the tools are not effective, then changes in management should be made and additional planning and scientific research may be necessary. This section provides an outline of the recovery program. The Narrative of Recovery Actions (Section 2.4) discusses the outline in more detail. The listing factor(s) (see Section 1.1 and Table 1) to be addressed by the recovery actions listed below are identified in parenthesis after each action.

1.0 Water Quality

1.1 Minimize catastrophic water quality threats

1.1.1. Identify, field verify, and map stream crossings and major recharge features and potential sources of catastrophic spills (A)

1.1.2. Develop a comprehensive database to track potential sources of spills that occur in the Barton Springs watershed (A)

1.1.3. Develop and implement a catastrophic spill avoidance plan (A)

1.1.4. Develop and implement a comprehensive regional spill containment and remediation plan (A)

1.1.5 Implement effective maintenance procedures for existing and future spill containment structures (A)

1.2 Avoid chronic water quality degradation

1.2.1 Develop and implement a regional approach to water quality protection that encompasses the entire Barton Springs watershed (A, D)

1.2.2 Maintain a comprehensive water quality database for the Barton Springs watershed to house water quality information. Evaluate the data to identify adaptive management actions to ensure long term water quality protection (A)

1.2.3 Design hypothesis-driven monitoring of physical and chemical constituents (sediment, nutrients, and contaminants) present during baseflow and stormflow conditions

1.2.3.1 Evaluate sediment quality at specific sites throughout the Barton Springs watershed (A)

1.2.3.2 Determine chronic and acute contaminant transport through the Aquifer and potential interactions with salamander habitat (A)

1.2.3.3 Conduct baseflow, stormwater, and biological monitoring at the springs and at sites throughout the Barton Springs contributing and recharge zones (A)

1.2.4 Gather information needed to assess adequacy of pollution control measures designed to prevent the degradation of water quality at Barton Springs

1.2.4.1 Monitor and evaluate the compliance of existing regulations requiring the use of BMPs and the effectiveness of new and existing BMPs on minimizing sediment and other contaminant input into the Aquifer (A, D)

1.2.4.2 Monitor and evaluate the effectiveness of pollution mitigation programs (A)

1.2.4.3 Evaluate buffer zone size and location for sensitive environmental features (A)

1.2.4.4 Implement programs to protect critical environmental features (caves, sinkholes, fissures, springs, and riparian zones) (A)

1.2.4.5 Reduce pollutant loading from existing development and transportation infrastructure (A)

1.2.5 Develop, implement, and modify programs to identify and correct problems from point and non-point source discharges (A)

1.2.6 Use existing information and conduct research to determine the potential effects of different levels of water quality constituents on the Barton Springs salamander, its prey base, and its habitat (A)

1.2.7 Develop and implement a land preservation strategy for the Barton Springs watershed (A)

2.0 Water Quantity

2.1 Gather and evaluate information necessary to ensure adequate water quantity

2.1.1 Determine Aquifer characteristics and recharge patterns (A)

2.1.2 Develop a Barton Springs watershed model to predict effects of increasing impervious cover, flooding, and groundwater pumping (A)

2.1.3 Monitor Aquifer and springflow levels under normal and drought conditions (A)

2.1.4 Monitor bad water line encroachment under low flow conditions (A)

2.1.5 Investigate Aquifer recharge enhancement potential in the recharge and contributing zones (A)

2.1.6 Refine understanding of water quantity requirements for the Barton Springs salamander and determine withdrawal volumes and Aquifer levels that will maintain adequate springflow (A)

2.1.7 Refine understanding of water balance within the Barton Springs segment so major sources of recharge can be better located and quantified (A)

2.2 Design, implement, and when needed, modify measures to provide adequate water quantity to Barton Springs

2.2.1 Develop and implement a regional Aquifer Management Plan using Barton Springs watershed model predictions to ensure protection of Aquifer levels and springflows under normal and drought conditions (A, D)

2.2.2 Develop, implement, and modify measures to protect existing recharge features from plugging and filling (A)

3.0 Surface Habitat Management

3.1 Maintain a comprehensive database on the spring habitats of the Barton Springs salamander (A)

3.2 Monitor the health and stability of the salamander prey base (A)

3.3 Implement research programs to further study the habitat requirements of the Barton Springs salamander (A)

3.4 Continue to monitor, manage, and provide protection for existing spring habitats, and modify management actions when new information warrants changes (A)

4.0 Salamander Monitoring and Research

4.1 Implement research programs to determine the life history characteristics (for example, fecundity, mortality, longevity, age/size at maturity, and growth rate) that govern population dynamics (such as, intrinsic rate of increase/decrease and population viability) of the Barton Springs salamander

4.1.1 Monitor Barton Springs salamander populations in the wild to ensure long term stability and viability (A, D, E)

4.1.2 Explore and develop marking techniques and conduct mark/recapture research (E)

4.1.3 Determine gene flow and migration between the four spring sites and genetic variation within, and among, the sites (E)

4.1.4 Investigate effects of various flow levels, especially low flows, on the salamander and the spring ecosystem (A, D, E)

4.1.5 Investigate the reproductive characteristics of the Barton Springs salamander (E)

4.1.6 Investigate the genetic characteristics and variation in the Barton Springs salamander at the individual and population level (E)

4.2 Investigate the prevalence and character of gas saturation in the water of spring habitats in the Barton Springs ecosystem (A)

4.3 Determine the short and long term impacts of gas bubble trauma on the Barton Springs salamander (A)

4.4 Develop and implement actions that prevent, avoid, and/or minimize the effects of gas bubble trauma on the Barton Springs salamander and other aquatic life in the spring ecosystem (A)

5.0 Captive Breeding

5.1 Develop a comprehensive Barton Springs salamander captive propagation and contingency plan consistent with the Service's *Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act* (A, E)

5.2 Develop dependable captive breeding and reintroduction techniques (A, E)

5.3 Establish, maintain, and monitor captive breeding populations to maintain adequate captive populations (A, E)

6.0 Public Outreach and Education

6.1 Develop, evaluate, and update education and outreach programs and materials to increase public awareness about the Barton Springs salamander and its habitat (A)

6.2 Develop, evaluate, and disseminate information about how to avoid spills and other sources of water quality degradation within the Barton Springs watershed (A)

7.0 Post-delisting monitoring

7.1 Develop a post-delisting monitoring plan for the Barton Springs salamander (A, E)

2.4 Narrative of Recovery Actions

Underlined recovery actions represent the most stepped-down levels of the Recovery Program Outline and Narrative. These items are discrete, specific actions and are the actions listed in the Implementation Schedule (Section 4.0).

1.0 Water Quality

1.1 Minimize catastrophic water quality threats

Information should be gathered and evaluated to design measures to avoid catastrophic water quality degradation. These measures should be implemented and modified, as necessary. Plans should be developed, implemented and, as necessary, modified to avoid, or contain and remediate catastrophic spills within the Barton Springs watershed.

1.1.1. <u>Identify, field verify, and map stream crossings and major recharge features and potential sources of catastrophic spills</u>

Mapping and field verification of all major recharge features is vital to protection of the Aquifer and the salamander. Because hazardous cargo routes have not been identified for the City of Austin and surrounding jurisdictions within the Barton Springs watershed, hazardous materials may be transported on any major roadway in the area. Teams of surveyors and hydrologists from local and regional agencies should compile a comprehensive map that identifies all roadways and drainage conveyance systems near Barton Springs watershed streams and major recharge features that have the potential to rapidly transport pollutants from a spill site to Barton Springs, and their hydrologic connection to the Aquifer.

To date, no agency or group of agencies has completed a comprehensive and detailed map of the existing infrastructure components that are potential sources of catastrophic spills. The comprehensive mapping of potential spill sources should include pipelines, underground storage tanks, and both sanitary and stormwater sewer systems. The mapping project should also include stream crossings, major recharge features, and critical environmental features that may provide rapid conveyance of pollutants to the springs. This information along with the information collected through the implementation of action 1.1.2 should be used to analyze the risk of a catastrophic spill occurring within the Barton Springs watershed.

1.1.2 Develop a comprehensive database to track potential sources of spills that occur in the Barton Springs watershed

The City of Austin and surrounding jurisdictions within the Barton Springs watershed, in conjunction with the BS/EACD and TCEQ, should use information gathered through action 1.1.1 to develop a comprehensive database to monitor and track the potential sources of spills as well as actual spills in both the recharge and contributing zones of the watershed. This information should be used to analyze the risk of a catastrophic spill occurring within the Barton Springs watershed and to develop a catastrophic spill avoidance plan (action 1.1.3) and a regional spill containment and remediation plan (action 1.1.4) and to collect the information necessary to evaluate and, as necessary, modify these plans.

1.1.3. Develop and implement a catastrophic spill avoidance plan

A plan to avoid catastrophic spills of pollutants and/or contaminants within the Barton Springs watershed should be developed and implemented. The routing of hazardous cargoes away from the recharge zone and critical environmental features would greatly diminish the potential for a catastrophic spill to threaten water quality of the springs and survival of the Barton Springs salamander. Travis County, the City of Austin, TCEQ, and TXDOT, and all jurisdictions within the Barton Springs watershed should identify appropriate hazardous material routes that do not cross the Barton Springs recharge zone, mark them accordingly, and require their use. Measures required by various regulatory agencies to prevent spills from pipelines, underground storage tanks, sewer systems, and other sources should be reviewed, evaluated, and, as necessary, updated. Information gathered from other actions under 1.1.5, 1.2.4, 1.2.5, and 1.2.6 of this outline should be helpful in preparing and implementing a catastrophic spill avoidance plan. Methodology for evaluating the effectiveness of this plan should be developed. The effectiveness of this plan should be monitored regularly and, as necessary, modified as new information and/or hazardous materials routes become available.

1.1.4. <u>Develop and implement a comprehensive regional spill containment and remediation plan</u>

The potential for a catastrophic spill to occur at or near Barton Springs, or within the recharge zone of the Barton Springs segment of the Edwards Aquifer, is a concern. A comprehensive regional spill response and remediation plan should be developed to address the potential impacts of on-site and off-site spills using information gathered in other actions in this plan. Once the plan has been completed, and a standard set of spill response protocols are developed, annual training sessions and trail runs for mock emergency spills should keep response personnel at an appropriate level of readiness. The effectiveness of this plan should be monitored regularly and, as necessary, modified.

To effectively address spill response issues, a thorough review of current spill remediation resources and training for on-site and off-site spills should be conducted. A review of resources and training should include the protocols of the Austin Fire Department, the City of Austin Watershed Protection Department's Water Quality Regulation Section (Spill and Response Team), the Texas Department of Transportation, TCEQ, the Texas Railroad Commission, and all jurisdictions within the Barton Springs watershed. Since response time can be the most critical factor for effective containment of a spill, a review of notification and communication protocols is also necessary.

Tracking the type, duration, and quantity of spills including information on when it was reported, who responded, and how long it took the response team to get to the scene, as well as what actions were taken will ensure the effectiveness of the containment and remediation plan. Debriefings should be held after a spill to determine how the plan and response can be improved. The spill response plan and team training should be revised accordingly, following post response debriefings.

This action is a logical extension of the mapping and field verification projects described above in actions 1.1.1 and 1.1.2. Data collected during the mapping and evaluation process will provide the framework for the proper location and design of spill containment structures and remediation features. These spill containment structures and remediation features should be placed in locations most needed for the protection of water quality.

1.1.5 <u>Implement effective maintenance procedures for existing and future spill containment structures</u>

Annual inspections of spill containment structures should take place and maintenance scheduled as needed. The need for possible retrofit of containment structures should also be considered.

1.2 Avoid chronic water quality degradation

Information should be gathered and evaluated to design measures that avoid chronic water quality degradation. Measures and programs to avoid chronic water quality degradation should be developed, implemented, and when needed, modified to ensure their effectiveness.

1.2.1 <u>Develop and implement a regional approach to water quality protection that encompasses the entire Barton Springs watershed</u>

There is no comprehensive plan in place that provides guidance for development throughout the Barton Springs watershed. Water quality protection throughout the Barton Springs watershed is currently under the jurisdiction of numerous local, state, and

Federal agencies. It is difficult to determine to what extent current local, state, and Federal water protection measures provide adequate protection, especially with rapid development and urban expansion. An assessment of the adequacy of current water quality protection mechanisms should be conducted as part of a regional plan. Assessment of the efficacy and adequacy of current protection measures such as TCEQ's Edwards Aquifer Rules should provide useful insight for the design and implementation of effective, comprehensive regional Aquifer protection measures. Developments receiving water from the first phase of the LCRA pipeline were built in accordance with the water quality protection recommendations developed by the Service and other parties in 2000. The effectiveness of these recommendations also should be evaluated.

Such a regional plan should use information resulting from Action 1.2.3.4 to develop specific recommendations for new and existing development throughout the Barton Springs watershed to minimize potential impacts to water quality before, during, and after construction. Through this approach, it should be determined if these recommendations should and can be adopted, implemented, and enforced by a single, state entity with jurisdiction over the entire Barton Springs watershed or by each of the local jurisdictions within the watershed. An evaluation of these two options should be conducted as these regulations are developed.

1.2.2 <u>Maintain a comprehensive water quality database for the Barton Springs watershed to house water quality information. Evaluate the data to identify adaptive management actions to ensure long term water quality protection</u>

Water quality at Barton Springs and in the Barton Springs watershed have been studied for decades by numerous state and local governmental agencies, as well as private and non-governmental groups. The most comprehensive water quality database for the Barton Springs watershed is maintained by the City of Austin and includes data collected by the City of Austin, TCEQ, and the USGS. The available data need to be analyzed and compiled into a comprehensive database available to all agencies, stakeholders, and interested parties. A comprehensive Barton Springs watershed database should provide the information necessary for the development of long term water quality protection. Analysis of the available information should be a coordinated, multi-agency effort with the goal of providing recommendations for long term water quality protection needs.

1.2.3 Design hypothesis-driven monitoring of physical and chemical constituents (sediment, nutrients, and contaminants) present during baseflow and stormflow conditions. Evaluate the data to determine specific water quality constituents that affect the Barton Springs salamander, including effects on its prey base and habitat.

Information should be collected on the physical and chemical constituents of greatest concern during baseflow and stormflow conditions. This information should include the amount of point and non-point source discharges entering the Barton Springs segment of the Edwards Aquifer and be used to design programs that will minimize pollution. Analyses should be conducted on this information to determine specific water quality constituents that affect the Barton Springs salamander.

1.2.3.1 Evaluate sediment quality at specific sites throughout the Barton Springs watershed

Sediment samples collected by the City of Austin in the Barton Springs watershed have contained high levels of various petroleum byproducts including PAHs and heavy metals, as well as various pesticides. These sediments with their adsorbed pollutants may settle in areas of primary salamander habitat, possibly exposing the species to chronic or even acute levels of specific pollutants. The sediment sampling effort should be expanded to locate specific sites or subwatersheds that contribute significant amounts of pollutants to the Aquifer and the sediments that discharge at Barton Springs.

1.2.3.2 Determine chronic and acute contaminant transport through the Aquifer and potential interactions with salamander habitat

Contaminant transport through the Aquifer occurs with the movement of groundwater, stormwater, and sediment. The contaminants may enter the Aquifer at levels that produce chronic impacts on the biota of the springs or acute impacts (catastrophic spill or pipeline rupture). More information is needed concerning the pathways and rate of contaminant transport within the Aquifer. Additional studies should be designed to define major conduits and the rate at which pollutants are either transported or deposited within the Aquifer. These studies should include testing during varying flow conditions to determine the impact of Aquifer levels on pollutant transport.

1.2.3.3 Conduct baseflow, stormwater, and biological monitoring at the springs and at sites throughout the Barton Springs contributing and recharge zones

Although a vast amount of data is available for the Barton Springs watershed, continued monitoring of surface and groundwater during baseflow and stormflow conditions is vital to further the understanding of the Aquifer and the complex hydrogeological and biological mechanisms affecting water quality, water quantity, habitat condition, and ecosystem health for aquatic biota. Continued monitoring of existing data collection programs will help identify where information gaps may be, the effectiveness of threat management, and how best to address these through the feedback mechanism in the adaptive management process.

1.2.4 Gather information needed to assess adequacy of pollution control measures and implement pollution control measures designed to prevent the degradation of water quality at Barton Springs.

Information on pollution control measures such as BMPs, pollution mitigation programs, and riparian buffers should continue to be gathered and evaluated, and the use of such measures should be monitored for compliance and efficacy to ensure adequate water quality for the Barton Springs salamander.

1.2.4.1 Monitor and evaluate the compliance of existing regulations requiring the use of BMPs and the effectiveness of new and existing BMPs on minimizing sediment and other contaminant input into the Aquifer

New and existing development sites using best management practices should be monitored for compliance to minimize sediment movement off-site and the efficiency of the particular BMP used. Since the early 1980s, City of Austin watershed protection ordinances have required the design and installation of various types of BMPs to aid in the treatment and detention of stormwater runoff from development. Hazardous material traps have also been constructed at sites where major highways cross streams that recharge the Barton Springs segment of the Aquifer. The design and installation of these stormwater detention, filtration, sedimentation, and hazardous material BMPs have evolved with the monitoring and evaluation of their effectiveness in mitigating the quality and quantity of stormwater runoff. Developments that were built in accordance with the water quality protection recommendations (such as those receiving water from the first phase of the LCRA pipeline) developed by the Service and other parties in 2000 may provide a starting point in evaluating the effectiveness of BMPs. This monitoring program should continue and should be expanded to include all existing BMPs in the Barton Springs watershed. Information gathered as a result of monitoring should be used to determine the role of BMPs in the protection of water quality.

1.2.4.2 Monitor and evaluate the effectiveness of pollution mitigation programs

Along with the implementation of structural stormwater controls, the City of Austin and other governmental agencies have developed pollution mitigation programs to minimize the amount of pollutants that enter Central Texas surface and groundwater. These programs include permit requirements for businesses that generate significant amounts of contaminants, petroleum products recycling, and household hazardous water disposal; citizen monitoring groups; and public outreach and education. The effectiveness of these programs in preventing pollution of the Aquifer should be monitored and evaluated.

Information gathered as a result of monitoring should be used to determine the effectiveness of pollution mitigation programs.

1.2.4.3 Evaluate buffer zone size and location for sensitive environmental features

Recharge and sensitive environmental features such as caves, sinkholes, fissures, and dissolution chambers should be protected to maintain a high quality of water in the Aquifer. Buffer zone sizes, such as those used in the 2000 water quality protection recommendations developed by the Service and other parties and used in the construction of developments receiving water from the first phase of the LCRA pipeline should be evaluated to determine adequate slope, vegetation, and drainage area characteristics. These sizes should be modified if warranted by new information.

1.2.4.4 Implement programs to protect critical environmental features (caves, sinkholes, fissures, springs, and riparian zones)

Use of BMPs, buffer zones, impervious cover limits, conservation easements, land acquisition, and other tools are all important ways to protect critical environmental features throughout the Barton Springs watershed and ensure the quality of water recharging to the Aquifer and discharging from spring habitats of the salamander. Information gathered as part of other actions in this outline should be helpful in implementing this action.

1.2.4.5 Reduce pollutant loading from existing development and transportation infrastructure

Information should be gathered to determine to what extent existing development and transportation infrastructure contribute to water quality degradation at Barton Springs. Sites that lack water quality control mechanisms or have mechanisms that are no longer operational should be retrofitted where space is available and when it is cost-effective to do so.

1.2.5 Develop, implement, and modify programs to identify and correct problems from point and non-point source discharges

The amount of pollution from point source discharges (wastewater and stormwater outfalls, industrial discharges, runoff from parking lots and impervious cover, and regional detention pond discharges, leaking or ruptured pipelines, leaking underground storage tanks, and leaking sewer lines) entering the Barton Springs segment of the Edwards Aquifer should be minimized. The amount of pollution from non-point sources entering the Barton Springs segment should be identified and minimized. Studies should be conducted to determine which site-specific characteristics influence the amount of impervious cover that should be recommended in an area. Programs designed to educate the public about point and non-point source pollution should be expanded. Regulatory agencies should work with stakeholders from development, utilities, transportation, and other appropriate industries to create specific recommendations to minimize potential impacts on water quality before, during, and after construction. Programs to reduce the discharge of stormwater pollutants related to the use of pesticides, herbicides, effluent irrigation, and fertilizer should be developed, implemented, and updated regularly.

1.2.6 Use existing information and conduct research to determine the potential effects of different levels of water quality constituents on the Barton Springs salamander, its prey base, and its habitat

Water quality constituents that could negatively affect the Barton Springs salamander if they are introduced into its ecosystem should be identified based on water quality data from Barton Springs, within the Barton Springs watershed, and from available toxicity data. A comprehensive literature search and review should be conducted to summarize the available toxicological research on the Barton Springs salamander's prey base as well as aquatic macrophytes and native fishes found in the Barton Springs ecosystem. Once priority constituents have been identified, toxicity studies should be conducted to determine the full range (including the effects of durations, concentrations, and the combinations of these) of their potential effects and target threshold levels needed to ensure long term protection of the species. Research should also evaluate the sublethal effects (such as those relating to reproduction, egg development, growth, and other metabolic processes) of specific constituents and the effects of the interactions of the constituents (that is, the synergistic effects) on the Barton Springs salamander.

1.2.7 Develop and implement a land preservation strategy for the Barton Springs watershed

The preservation of undeveloped land within the Barton Springs watershed provides permanent protection for the Barton Springs salamander by reducing the threat of increased water quality degradation as a result of higher impervious cover caused by development. A strategy should be developed that outlines the amount of land in both the contributing and recharge zones of the Barton Springs watershed that should be protected and preserved through fee simple acquisitions, conservation easements, and/or deed restrictions and for evaluating which locations provide the most water quality benefits. This strategy also should include proposals for specific funding mechanisms for land acquisition.

2.0 Water Quantity

2.1 Gather and evaluate information necessary to ensure adequate water quantity

Additional information needs to be gathered and evaluated to ensure adequate water quantity in the Barton Springs segment of the Edwards Aquifer at levels that protect the Barton Springs salamander and its habitat.

2.1.1 Determine Aquifer characteristics and recharge patterns

The City of Austin and BS/EACD dye tracing efforts should be continued to further examine groundwater divides (particularly the southern divide), sources and pathways of contamination (action 1.2.3.2), and to more precisely locate the preferred groundwater flow paths along which most of the groundwater transported converges.

2.1.2 Develop a Barton Springs watershed model to predict effects of increasing impervious cover, flooding, and groundwater pumping

Due to the complex nature of the interactions between surface and groundwater, and the effects of increasing impervious cover, flooding, and groundwater removal on Aquifer pathways and hydraulics, predictive models should be useful tools to determine the potential impacts of future development throughout the Barton Springs watershed. Modeling of the Barton Springs watershed should be expanded to include accurate estimates of flow rates and water quality constituent concentrations under varying development and water pumping scenarios to determine how they might influence springflow. The Center for Research in Water Resources Parsimonious Model (Barrett and Charbeneau 1996) provides an excellent starting point for the development of the predictive watershed model.

2.1.3 Monitor Aquifer and springflow levels under normal and drought conditions

Continuous data loggers as well as site visits should be used to monitor and assess Aquifer and springflow levels under normal and drought conditions to ensure that activities implemented under action 2.2.1 are resulting in adequate flow levels. This information should be used in developing and refining models mentioned in this outline under actions 2.1.2 and 2.1.7.

2.1.4 Monitor bad water line encroachment under low flow conditions

When Aquifer and springflow are in low flow conditions, movement of the "bad water line" (also referred to as the saline water interface) should be monitored. Information gathered as a result of monitoring should be used to implement measures, if necessary, to ensure adequate water quantity.

2.1.5 Investigate Aquifer recharge enhancement potential in the recharge and contributing zones

Opportunities exist throughout the recharge and contributing zones to design and construct recharge enhancement features. One proposal is to construct large detention facilities in the Onion Creek watershed. These structures would minimize the level of flooding along downstream sections of Onion Creek and also increase the Aquifer recharge potential in the recharge zone. All six contributing streams in the Barton Springs watershed need to be evaluated for recharge enhancement potential.

Aquifer recharge enhancement may be a useful tool in future years to help offset the impacts of drought, increased surface runoff due to expanding development, and increased pumping from the Aquifer. However, careful consideration of these projects should be given to the potential for introducing poor water quality back into the Aquifer and potential impacts to the native terrestrial biota (for example, karst invertebrates) that may inhabit the recharge features.

2.1.6 Refine understanding of water quantity requirements for the Barton Springs salamander and determine withdrawal volumes and Aquifer levels to maintain adequate springflow

Barton Springs have never ceased flowing in recorded history. However, with increases in the level of development on the watershed it will be more difficult to ensure that flow levels will be maintained. The level of flow required to support the continued existence of the aquatic community at Barton Springs should be defined. Neither the optimal nor critical flow levels have been determined. These flow levels should be determined, evaluated regularly, and refined, as necessary.

2.1.7 Refine understanding of water balance within the Barton Springs segment so major sources of recharge can be better located and quantified

Estimates of water balance within the Barton Springs segment should be refined based on source areas delineated by groundwater tracing, longer continuous flow measurements upstream and downstream of each major creek channel, measurements of evapotranspiration, flow measurements from typical upland drainage sinkholes, rainfall, and pumping levels.

2.2 Design, implement, and when needed, modify measures to provide adequate water quantity to Barton Springs

Droughts are a natural occurrence in Central Texas. The effects of droughts on the Edwards Aquifer, however, may be worsened by development and other human activities on the watershed. To protect the ecosystem at Barton Springs, a comprehensive approach to management in the Barton Springs segment would be beneficial in protecting water quantity.

2.2.1 Develop and implement a regional Aquifer Management Plan using Barton Springs watershed model predictions to ensure protection of Aquifer levels and springflows under normal and drought conditions

Local governments should work together with the public and state and Federal agencies to develop measures to ensure protection of Aquifer levels and springflows. Although the BS/EACD continues to manage well pumping, a comprehensive regional plan that addresses water quantity threats to the Aquifer should be developed and implemented to provide protection throughout the contributing and recharge zones. Groundwater pumping limits should be addressed and outlined in this plan. Vegetation management practices that can be used to maintain native plant and animal community composition in the recharge zone and allow for the most beneficial effects to water quantity also should be evaluated and addressed in this plan. The BS/EACD would be a good candidate to take a lead role in developing these protection measures.

2.2.2 Develop, implement, and modify measures to protect existing recharge features from plugging and filling

Major recharge features in the creek channels are easily plugged by sediment and debris, particularly downstream of disturbed areas. While most of the Aquifer recharge occurs within the creek channels, some recharge enters the Aquifer through sinkholes, caves, dissolution cavities, and other features in the upland areas. Efficient upland recharge is important because the creeks have limited infiltration capacities, causing the rejected flows to leave the recharge zone as downstream runoff. The destruction, plugging, or filling of recharge features and the loss of natural drainage features can have long term impacts on water quantity in the Barton Springs segment of the Edwards Aquifer. Innovative and nondestructive methods of infiltrating high quality runoff (such as diverting drainages into existing, unused quarries and sinkholes, and opening sediment filled sinkholes in creek bottoms) should be developed, implemented, and, as necessary, modified. A plan detailing protection and restoration measures for these recharge features should be prepared to help sustain continuous spring flows.

3.0 Surface Habitat Management

3.1 Maintain a comprehensive database on the spring habitat of the Barton Springs salamander

The City of Austin maintains a database of monthly salamander survey data. This database should continue to include comprehensive information about the spring ecosystem, such as substrate composition, plant/animal composition, and the effects of management practices on the spring sites. The Service and City of Austin should conduct an annual review of this database and change salamander and/or spring ecosystem management as necessary.

3.2 Monitor the health and stability of the salamander prey base

Data exist on the food habits of the Barton Springs salamander, but additional information is needed to assure adequate management of the species and its habitat. The distribution, abundance, and microhabitat preferences of potential prey items should be studied, as well as the nature and degree of prey selection by the Barton Springs salamander.

3.3 Implement research programs to further study the habitat requirements of the Barton Springs salamander

The City of Austin, Service, and other appropriate parties should continue monitoring and research to determine the reproductive, nutritional, and ecological requirements of the Barton Springs salamander. Data on habitat features necessary for survival and reproduction will improve long term management of the species. Although general habitat features are known, more information is needed about the characteristics and breadth of the niche occupied by these salamanders, their position in the food web and their interaction with the aquatic ecosystem as a whole. This type of information is required to develop effective long term management of the species.

3.4 Continue to monitor, manage, and provide protection for existing spring habitats, and modify management actions when new information warrants changes

The City of Austin should continue its efforts to protect, manage, and restore the four spring sites using information maintained in the database described in action 3.1, primary scientific literature, and salamander research. Monitoring data also should be used to modify the current measures to protect salamander habitat if warranted.

4.0 Salamander Monitoring and Research

4.1 Implement research programs to determine the life history characteristics (for example, fecundity, mortality, longevity, age/size at maturity, and growth rate) that govern population dynamics (such as, intrinsic rate of increase/decrease and population viability) of the Barton Springs salamander

Additional life history and demographic data are needed to accurately assess the status and long term trends of Barton Springs salamander populations and to effectively manage captive populations. Studies should include determining if subsurface movement occurs among the four springs sites; accurately estimating effective population size, extinction probabilities, sex ratios in the wild, fecundity ratio (percent of females producing offspring at any one point in time), and percent of breeding males; and determining if breeding is density-dependent.

4.1.1 <u>Monitor Barton Springs salamander populations in the wild to ensure long term stability and viability</u>

Information on the number of juveniles and adults found at each spring site should continue to be collected during the City of Austin's monthly surveys. These data should be analyzed and the results used to identify and implement measures that will ensure adequate reproduction is occurring and whether the objective of maintaining a stable or increasing population has been obtained.

4.1.2 <u>Explore and develop marking techniques and conduct mark/recapture research</u>

Mark and recapture methods are a useful approach to identifying and tracking individual salamanders in the wild population. These data can also be used to estimate population size, growth rates and mortality, and document territorial behavior or migration events between different spring sites. The ability to track and identify animals as small as the Barton Springs salamander poses unique challenges. Standard methods used for larger animals such as radio-tracking and PIT (passive integrated transponder) tagging are currently not feasible for the salamander. City of Austin biologists have developed an identification technique based on photographing external pigment patterns. The technique appears to be feasible in the field, but is time-consuming. Existing and new marking techniques should be explored and evaluated for utility and efficiency in studying the Barton Springs salamander.

4.1.3 Determine gene flow and migration between the four spring sites and genetic variation within and among the sites

Using information developed from genetic research (4.1.6) and mark/recapture (4.1.2) actions, salamander migration among the four spring habitats should be evaluated to determine if the populations are discrete or part of a larger metapopulation (constellation of local populations linked by dispersal). If salamanders are found to move between sites, efforts should be made to determine what influences preference for one site over another (for example, seasonal changes, water quality, or gas saturation). This information is also needed to determine whether captive populations should continue to be maintained separately by spring site or pooled to increase genetic diversity.

4.1.4 Investigate effects of various flow levels, especially low flows, on the salamander and spring ecosystem

The City of Austin should continue monthly monitoring of salamander populations at all four spring sites and quantify changes in the composition of the ecosystem. The relationship of changes to flow conditions should be analyzed and the potential long term effects of water quantity on salamander abundance should be evaluated. This information should be used to develop and implement management practices that will ensure adequate water quantity to support a stable salamander population and ecosystem.

4.1.5 Investigate the reproductive characteristics of the Barton Springs salamander

Information on the reproductive characteristics of the salamander is needed to better understand the dynamics of population change and to evaluate the positive or negative effects of environmental factors in species recovery. Fecundity, fecundity ratio (that is, the number of females in the population that are gravid at any one time), reproductive seasons, if any, oviposition (egg-laying) behavior and site selection, factors influencing egg hatching, larval growth characteristics, influence of nutrient availability on reproductive success, and others are important aspects of reproduction that will contribute to effective management of wild populations and further the development of the Captive Propagation and Contingency Plan (action 5.1).

4.1.6 Investigate the genetic characteristics and variation in the Barton Springs salamanders at the individual and population level

Genetic analyses will help determine the effective size of the current population of the Barton Springs salamander and its potential to adapt to changes in the environment. This type of information will also contribute to understanding the movement patterns between the four springs sites and whether individuals from different sites interbreed. The City of Austin should continue to work closely with salamander and captive breeding experts to further understand the genetic diversity of the species and foster cooperative research with other institutions to increase knowledge of the species. Continued research is also essential in designing the Captive Propagation and Contingency Plan (action 5.1) and a re-introduction program so that captive populations adequately represent the genetic characteristics of the wild population.

4.2 Investigate the prevalence and character of gas saturation in the water of spring habitats in the Barton Springs ecosystem

Evidence of supersaturation of water at all four spring sites was noted in 2002 after the discovery of salamanders with gas bubble trauma. The elevation of supersaturation rates was particularly pronounced at Upper Barton Springs, which lies along a more urbanized flow path. Baseline data on the temporal and spatial variation of dissolved gases at Barton Springs and other springs in the Edwards Aquifer, including the northern segment and San Antonio segment, should be analyzed. Weekly collection of temperature, pH, gas saturation, and gas composition should continue as part of the City of Austin's monitoring program until the causes, effects, and prevention of gas bubble trauma are determined.

4.3 Determine the short and long term impacts of gas bubble trauma on the Barton Springs salamander

February 2002 was the first time salamanders and other animals affected by gas bubble trauma were documented at Barton Springs. The majority of affected animals were found at Upper Barton Springs, which had the highest supersaturation among Barton Springs salamander sites. Multiple species were affected, and veterinary pathologists found no evidence of a pathogenic cause. However, it is unclear to what extent the condition may have been present in the population previously because affected salamanders may be difficult to find due to predation and/or decomposition. Laboratory experiments should be conducted using similar species to identify probable acute and chronic effects of gas bubble trauma on Barton Springs salamanders. Searches of the spring areas for salamanders and other aquatic animals with gas bubble trauma should be collected. Any live salamanders found in bloated condition should be maintained in the City of Austin's captive breeding facility and monitored for recurrence of the condition or complicating factors. Dead salamanders should be preserved for use in genetic research (action 4.1.6) and investigation into the potential for a genetic basis of susceptibility to gas bubble trauma.

4.4 Develop and implement actions that prevent, avoid, and/or minimize the effects of gas bubble trauma on the Barton Springs salamander and other aquatic life in the spring ecosystem

After the cause(s) and prevalence of gas bubble trauma is determined, the City of Austin and other appropriate entities should use information gathered from this and action 4.4 to develop and implement measures that prevent, avoid, or minimize gas bubble trauma in Barton Springs salamanders and other aquatic life in the spring ecosystem.

5.0 Captive Breeding

5.1 Develop a comprehensive Barton Springs salamander captive propagation and contingency plan consistent with the Service's *Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act*

A comprehensive Captive Propagation and Contingency Plan (CPCP) should be developed to establish captive maintenance and breeding programs and a re-introduction strategy for the Barton Springs salamander. The goal of the captive propagation portion of the CPCP will be to outline the steps necessary to provide a secure representation of the genetic characteristics of the wild population should re-introduction be necessary. Although holding individuals in captivity is not a substitute for maintaining the species by protecting the ecosystem on which it depends, a captive maintenance program is important for this species for maintaining stock should a large scale die-off take place in the wild. Additionally, the development of captive breeding techniques will provide an opportunity to identify additional information on the biology of the species, including early life stage characteristics.

The contingency portion of the CPCP also will establish the collection targets and protocols needed to respond to crisis situations. Contingency planning should not be delayed until the completion of genetic, breeding, and re-introduction studies, but should be updated as these studies are completed. The CPCP should be developed in coordination with agencies that would likely be involved with the collection efforts, including the City of Austin, Texas Parks and Wildlife Department, Service, and experts from academic institutions with expertise in determining collection levels that will represent enough genetic diversity to keep the population viable. City of Austin staff are developing a "salamander rescue" plan to be used in the event of a catastrophic spill and will modify this plan as new information becomes available.

The CPCP needs to address three situations: (1) captive rearing of animals during non-crisis times in the event of a rapidly developing crisis when there is no time to collect wild animals; (2) collection and captive rearing of animals as a response to a rapidly developing crisis in which there is time to collect additional wild animals; and (3) collection and captive rearing of animals in response to a slowly developing crisis. A commitment to long term management of a captive population is needed due to the limited range of the species and the on-going potential of a catastrophic event occurring at the spring sites that could significantly impact the salamander population.

The City of Austin has established a captive breeding program for the Barton Springs and Austin blind salamanders and is committed to its continued funding and operation. City of Austin biologists are working with the American Zoo and Aquarium Association to develop a plan to manage the breeding of the species to maintain a viable population that is both genetically diverse and demographically stable. The City of Austin should continue to develop the captive management plan and the "salamander rescue" plan. These plans will provide a foundation for the CPCP.

Identifying facilities interested in participating in both the captive propagation and contingency portions of the CPCP is necessary for its success. Because the City of Austin operates, manages, and monitors the springs, any salamander collection efforts would need to be coordinated with the City of Austin. Institutions involved in collection efforts would need to hold appropriate state and Federal permits. For each facility, a Participation Plan should be developed in coordination with the Service and City of Austin that outlines the level of commitment to cooperate (long term versus short-term holding facilities), personnel willing to collect and transport animals, research to be conducted, and level of information to be collected. The CPCP and Participation Plans should be periodically re-assessed (for example, annually) and altered as necessary.

5.2 Develop dependable captive breeding and reintroduction techniques

Although the Barton Springs salamander has been bred in captivity, dependable techniques for controlled captive breeding have not been developed. These techniques need to be developed to ensure that offspring will be available for re-introduction should it be necessary. City of Austin biologists and other participants in the CPCP should continue to explore breeding techniques as well as detailed records on egg-laying events and salamander courtship behavior.

5.3 Establish, maintain, and monitor captive breeding populations to maintain adequate captive populations

Captive breeding populations should be established as quickly as possible in accordance with the CPCP. Maintenance of captive breeding facilities will likely be needed even after the species is delisted, to serve as back-up in the event of a catastrophic impact to the species. A commitment to maintain an adequate captive breeding program for the long term is necessary. The number of individuals in captivity and effectiveness of captive breeding programs should be monitored. Each captive breeding site should track the collection site (or collection site of parentage, if born in captivity), sex, reproductive condition, egg laying events, hatching, survivorship, and mortality information for each salamander. City of Austin biologists should continue to maintain detailed records in the Animal Records Keeping System, a global information network and information database used by zoos and managed by the International Species Information System.

In addition to requiring reliable breeding success, other factors to be considered in determining a long term viable population include potential impacts of diseases, genetic work to determine variability in the wild, age at first reproduction, percent of females producing young, percent of males in the breeding pool, clutch size, fecundity, factors influencing egg hatching and juvenile survivorship, and whether breeding is density-dependant. A general rule of thumb commonly obtained from conservation biology literature prescribes a minimum short-term effective population of 50 individuals to prevent unacceptable inbreeding and a minimum long term effective population of 500 to maintain overall genetic diversity (Franklin 1980, Soule 1980). Effective population generally refers to individuals that contribute offspring to a population. Thus, if only 10 percent of the individuals in a population reproduce, the 50/500 rule would translate to a short-term minimum viable population of over 500 individuals. Adequate space, equipment, and water are critical to supporting a viable captive population. New information should be reviewed and monitored, including the implementation of new study techniques. Captive breeding programs should be modified when new information becomes available.

6.0 Public Outreach and Education

6.1 Develop, evaluate, and update education and outreach programs and materials to increase public awareness about the Barton Springs salamander and its habitat

The Austin Science and Nature Center operates the "Splash!" Exhibit and other programs designed to educate the public on the salamander and the Edwards Aquifer. These efforts should be continued and updated regularly as new information becomes available. Efforts to develop new outreach materials on the salamander, the Aquifer, good land-use practices, and water quality should be encouraged and supported.

6.2 Develop, evaluate, and disseminate information about how to avoid spills and other sources of water quality degradation within the Barton Springs watershed

Whether it is information about how to responsibly recycle potentially hazardous household materials like engine oil, batteries, and pest control substances or information about new technology available to be used by dry cleaners or oil and gas companies, continued education on how individuals and corporations can do their part to ensure spills and other contaminants do not reach the Aquifer is important. Outreach efforts by the City of Austin, TCEQ, local businesses, and others should be encouraged, supported, and expanded where possible.

7.0 Post-delisting monitoring

7.1 Develop a post-delisting monitoring plan for the Barton Springs salamander

Section 4 (g) (1) of the ESA requires that the Service monitor the status of all recovered species for at least five years following delisting. In keeping with this mandate, a post-delisting monitoring plan should be developed by the Service in cooperation with Texas Parks and Wildlife Department, the Barton Springs Salamander Recovery Team, Federal agencies, academic institutions, and other appropriate entities. This plan should outline the indicators that will be used to assess the population status of the Barton Springs salamander, develop monitoring protocols for those indicators, and evaluate factors that may trigger consideration for relisting.

3.0 LITERATURE CITED

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4.0 IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for implementing this recovery plan. It is a guide for meeting the objectives discussed in the recovery section (Section 2.0) of this plan. This schedule indicates action priorities, action numbers, action descriptions, duration of actions, potential partners, and estimated costs. These actions, when complete, should accomplish the objectives of this plan. The Service has identified agencies and other potential partners to help implement the recovery of these species. This plan does not commit any partners to actually carry out a particular recovery action or expend the estimated funds. Likewise, this schedule does not preclude or limit other agencies or parties from participating in the recovery program.

The estimated cost of recovery, according to each priority, is provided in the Executive Summary, not in the Implementation Schedule. In the Implementation Schedule, the estimated monetary needs for all parties involved in recovery are identified for the first 3 years only. Estimated funds for agencies include only project specific contract, staff, or operations costs in excess of base budgets. They do not include budgeted amounts that support ongoing agency staff responsibilities.

Cost for some actions in the recovery plan are not yet determinable, because they depend on the nature of the strategies selected for use. These actions where expenses cannot yet be calculated are represented in the costs column with the designation NYD for “not yet determinable”.

The term “continuous” is used to denote actions that are expected to require constant attention throughout the recovery process, and therefore have an indefinite duration. The term “ongoing” is used in the recovery plan to identify actions that have already been started, but are not yet complete.

Priorities in column one of the following implementation schedule are assigned using the following guidelines:

Priority 1(a) - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the *foreseeable* future.

Priority 1(b) - An action that by itself will not prevent extinction, but which is needed to carry out a Priority 1(a) action.

Priority 2 - An action necessary to prevent a significant decline in species population/habitat quality, or some other significant negative impact short of extinction.

Priority 3 - All other actions necessary to meet the recovery objectives.

Actions and action numbers are taken from the Recovery Action Outline and Recovery Action Narrative (sections 2.3 and 2.4). The terms and acronyms used for the potential partners for implementation are listed below:

BS/EACD	Barton Springs/Edwards Aquifer Conservation District
CoA	City of Austin
EPA	U.S. Environmental Protection Agency
HCo	Hays County
LCRA	Lower Colorado River Authority
NRCS	Natural Resource Conservation Service
TxDoT	Texas Department of Transportation
TXSt	Texas State University-San Marcos
TCEQ	Texas Commission on Environmental Quality
TCo	Travis County
TPWD	Texas Parks and Wildlife Department
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UT	University of Texas at Austin

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	1.1.3	Develop and implement a catastrophic spill avoidance plan	2 to develop; continuous	TxDOT, TCEQ, EPA, HCo, TCo, CoA, and other jurisdictions, USFWS	80	40	10	10	10	10	
1(a)	1.1.4	Develop and implement a comprehensive regional spill containment and remediation plan	2 to develop; continuous	CoA and other jurisdictions, TCEQ, EPA, TxDOT, HCo, & TCo	110	30	20	20	20	20	
1(a)	1.1.5	Implement effective maintenance procedures for existing and future spill containment structures	continuous	CoA and other jurisdictions, TCEQ, EPA, TxDOT, HCo, & TCo	70	30	10	10	10	10	
1(a)	1.2.1	Develop and implement a regional approach to water quality protection that encompasses the entire Barton Springs watershed	2 to develop; continuous	CoA and other jurisdictions, HCo, TCo, LCRA, BS/EACD, TxDOT	280	200	20	20	20	20	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	1.2.4.4	Implement programs to protect critical environmental features (caves, sinkholes, fissures, springs, and riparian zones)	continuous	CoA and other jurisdictions, TCEQ, EPA, USFWS	175	75	25	25	25	25	
1(a)	1.2.4.5	Reduce pollutant loading from existing development and transportation infrastructure	continuous	CoA and other jurisdictions, HCo, TCo, LCRA, TxDOT	250	50	50	50	50	50	
1(a)	1.2.5	Develop, implement, and modify programs to identify and correct problems from point and non-point source discharges	3 to develop; continuous	CoA and other jurisdictions, TCEQ, EPA, USFWS	225	90	45	30	30	30	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	1.2.6	Use existing information and conduct research to determine the potential effects of different levels of water quality constituents on the Barton Springs salamander, its prey base, and its habitat	3	CoA, EPA, TCEQ, USFWS, HCo, TCo, and other jurisidictions	150	100	50				
1(a)	2.2.1	Develop and implement a regional Aquifer Management plan using Barton Springs watershed model predictions to ensure protection of Aquifer levels and springflows under normal and drought conditions	2 to develop; continuous	BS/EACD, EPA, TCEQ, CoA, USFWS	75	35	10	10	10	10	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(a)	2.2.2	Develop, implement, and modify measures to protect existing recharge features from plugging and filling	2 to develop; continuous	BS/EACD, EPA, TCEQ, CoA, USFWS	110	50	15	15	15	15	
1(a)	3.4	Continue to monitor, manage, and provide protection for existing spring habitats, and modify management actions when new information warrants changes	ongoing	CoA, TPWD, USFWS	250	50	50	50	50	50	
1(a)	5.3	Establish, maintain, and monitor captive breeding populations to maintain adequate captive populations	ongoing; continuous	CoA, USFWS, and other appropriate entities	225	45	45	45	45	45	should be performed in accordance with action 5.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.1.1	Identify, field verify, and map stream crossings and major recharge features and potential sources of catastrophic spills	2	TxDOT, TCEQ, EPA, HCo, TCo, CoA, and other jurisdictions	50	50					supports actions 1.1.3 and 1.1.4
1(b)	1.1.2	Develop a comprehensive database to track potential sources of spills that occur in the Barton Springs watershed	2 to develop; continuous	TxDOT, TCEQ, EPA, HCo, TCo, CoA, and other jurisdictions, USFWS	130	50	20	20	20	20	supports actions 1.1.3 and 1.1.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.2	Maintain a comprehensive water quality database for the Barton Springs watershed to house water quality information and evaluate the data to use in adaptive management actions to ensure long term water quality protection	continuous	TCEQ, EPA, USGS, USFWS, TPWD, UT, CoA and other jurisdictions	100	20	20	20	20	20	supports actions 1.2.1 and 3.4
1(b)	1.2.3.1	Evaluate sediment quality at specific sites throughout the Barton Springs watershed	continuous	USGS, TCEQ, EPA, LCRA, TxDOT, CoA	125	25	25	25	25	25	supports actions 1.2.1 and 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.3.2	Determine chronic and acute contaminant transport through the Aquifer and potential interactions with salamander habitat	2	USGS, TCEQ, EPA, LCRA, TxDOT, CoA, TPWD, BS/EACD	50	50					supports actions 1.2.1 and 3.4
1(b)	1.2.3.3	Conduct baseflow, stormwater, and biological monitoring at the springs and at sites throughout the Barton Springs contributing and recharge zones	continuous	USGS, TCEQ, EPA, LCRA, TxDOT, CoA, TPWD, BS/EACD	120	20	20	20	20	20	supports actions 1.2.1 and 3.4
1(b)	1.2.3.4	Gather new and existing toxicity data to evaluate the effects of specific constituents on the Barton Springs salamander and its prey base	3	USGS, TCEQ, EPA, LCRA, TxDOT, CoA, TPWD	60	40	20				supports action 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.4.1	Monitor and evaluate the compliance of existing regulations requiring the use of BMPs and the effectiveness of new and existing BMPs on minimizing sediment and other contaminant input into the Aquifer	continuous	TCEQ, EPA, CoA and other jurisdictions, LCRA, TxDOT, USGS	125	25	25	25	25	25	supports actions 1.2.1, 1.2.5, and 3.4
1(b)	1.2.4.2	Monitor and evaluate the effectiveness of pollution mitigation programs	continuous	TCEQ, EPA, CoA and other jurisdictions, LCRA, USGS	100	20	20	20	20	20	supports actions 1.2.1, 1.2.5, and 3.4
1(b)	1.2.4.3	Evaluate buffer zone size and location for sensitive environmental features	2	TCEQ, EPA, CoA and other jurisdictions, LCRA, USGS	30	30					supports actions 1.2.1, 1.2.5, and 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	1.2.7	Develop and implement a land preservation strategy for the Barton Springs watershed	2 to develop 10 to implement	CoA, HCo, TCo, and appropriate entities	60	60					supports actions 1.2.1 and 3.4 estimated cost is given only for strategy development; does not reflect cost associated with acquiring land
1(b)	2.1.1	Determine Aquifer characteristics and recharge patterns	ongoing; 2 to complete study	BS/EACD, CoA	30	30					supports action 2.2.1
1(b)	2.1.2	Develop a Barton Springs watershed model to predict effects of increasing impervious cover, flooding, and groundwater pumping	3	TCEQ, EPA, BS/EACD, CoA, USFWS, TPWD	60	40	20				supports action 2.2.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	2.1.3	Monitor Aquifer and springflow levels under normal and drought conditions	ongoing	TCEQ, EPA, BS/EACD, CoA, USFWS, USGS	100	20	20	20	20	20	supports action 2.2.1
1(b)	3.1	Maintain a comprehensive database on the spring habitats of the Barton Springs salamander	ongoing; continuous	CoA, USFWS, TPWD	100	20	20	20	20	20	supports action 3.4
1(b)	3.2	Monitor the health and stability of the salamander prey base	ongoing; continuous	CoA, USFWS, TPWD, TCEQ	100	20	20	20	20	20	supports action 3.4
1(b)	3.3	Implement research programs to further study the habitat requirements of the Barton Springs salamander	continuous	CoA, USFWS, TPWD, UT	200	40	40	40	40	40	supports action 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	4.1.1	Monitor Barton Springs salamander populations in the wild to ensure long term stability and viability	ongoing; continuous	CoA, USFWS, TPWD, UT	100	20	20	20	20	20	supports action 3.4
1(b)	4.1.2	Explore and develop marking techniques and conduct mark/recapture research	ongoing; 4 to complete	CoA, USFWS, TPWD, UT	50	25	25				supports action 3.4
1(b)	4.1.3	Determine gene flow and migration between the four spring sires and genetic variation within, and among, the sites	2	CoA, USFWS, TPWD, UT, USGS, BS/EACD	50	50					supports action 3.4
1(b)	4.1.5	Investigate the reproductive characteristics of the Barton Springs salamander	ongoing; 4 to complete	CoA, USFWS, TPWD, UT	80	40	40				supports actions 3.4 and 5.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
1(b)	4.1.6	Investigate the genetic characteristics and variation in the Barton Springs salamander at the individual and population level	4	CoA, USFWS, TPWD, UT	80	40	40				supports actions 3.4 5.1
1(b)	5.1	Develop a comprehensive Barton Springs salamander captive propagation and contingency plan consistent with the Service's *Policy Regarding Controlled Propagation of Listed Species Listed Under the Endangered Species Act*	4	CoA, UT, TXSt, USFWS	150	75	75				supports action 5.3
1(b)	5.2	Develop dependable captive breeding and reintroduction techniques	ongoing	CoA, UT, TXSt, USFWS	200	40	40	40	40	40	supports action 5.3

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
2	2.1.4	Monitor bad water line encroachment under low flow conditions	continuous	USGS, CoA, TCEQ, EPA	150	30	30	30	30	30	supports action 2.2.1
2	2.1.5	Investigate Aquifer recharge enhancement potential in the recharge and contributing zones	3	USGS, BS/EACD, CoA, TCEQ, EPA	90	60	30				supports action 2.2.1
2	2.1.6	Refine understanding of water quantity requirements for Barton Springs salamander and determine withdrawal volumes and Aquifer levels that will maintain adequate springflow	3	USGS, BS/EACD, CoA, TCEQ, EPA, TPWD, USFWS	90	60	30				supports action 2.2.1

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
2	2.1.7	Refine understanding of water balance within the Barton Springs segment so that major sources of recharge can be better located and quantified	3	USGS, UT BS/EACD, CoA, TCEQ, EPA	90	60	30				supports actions 2.2.1 and 2.2.2
2	4.1.4	Investigate effects of various flow levels, especially low flows, on the salamander and the spring ecosystem	continuous	CoA, BS/EACD, UT, USFWS, TPWD	125	25	25	25	25	25	
2	4.1.6	Investigate the food habits of the Barton Springs salamander	2	CoA, TPWD, USFWS	20	20					
2	4.2	Investigate the prevalence and character of gas saturation in the water of spring habitats in the Barton Springs ecosystem	4	TCEQ, EPA, UT, CoA, USFWS, TPWD, USGS, BS/EACD	100	50	50				supports action 3.4

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
2	4.3	Determine the short and long term impacts of gas bubble trauma on the Barton Springs salamander	2	TCEQ, EPA, UT, CoA, USFWS, TPWD, USGS,	40	40					supports action 3.4
2	4.4	Develop and implement actions that prevent, avoid, and/or minimize the effects of gas bubble trauma on the Barton Springs salamander and other aquatic life in the spring ecosystem	3 to develop; continuous	CoA, EPA, TCEQ, TPWD, USFWS	90	40	20	10	10	10	supports action 3.4
3	6.1	Develop, evaluate, and update education and outreach programs and materials to increase public awareness about the Barton Springs salamander and its habitat	ongoing continuous	CoA and other jurisdictions, USFWS, TPWD	125	25	25	25	25	25	

Implementation Schedule: Barton Springs Salamander Recovery Plan

Priority	Action Number	Action Description	Action Duration (Years)	Minimum List of Potential Partners	Total Estimated Cost ($1000s)	Estimated Costs ($1000s)					Comments
						Years 1-2	Years 3-4	Years 5-6	Years 7-8	Years 9-10	
3	6.2	Develop, evaluate, and disseminate information about how to avoid spills and other sources of water quality degradation within the Barton Springs watershed	ongoing; continuous	TCEQ, EPA, LCRA, NRCS, USDA, USFWS, TPWD, CoA and other jurisdictions, HCo, and TCo	250	50	50	50	50	50	
3	7.1	Develop a post-delisting monitoring plan for the Barton Springs salamander	3	USFWS, CoA, BS/EACD, TPWD, USGS, TCEQ, HCo, TCo, and other appropriate entities	150	30	30	30	30	30	

Appendix A - Degradation for selected water quality constituents at Barton Springs (City of Austin 2000).

		Normalized period median values			
Water quality Constituent	**Flow Condition**	**1975-1979 or 1980-1984**	**1995-1999**	**Change From Early to Late Period**	**Percent Change**
Specific conductance (microsiemens per centimeter)	Baseflow without recharge	655	677	22	+3%
	Baseflow with recharge	590*	646	56	+9%
	Storm flow	624	642	18	+3%
Dissolved oxygen (parts per million)	Baseflow without recharge	6.8	5.7	1.1	+16%
Total organic carbon (parts per million)	Storm flow	1.5	3.4	1.9	+127%
Sulfate (parts per million)	Baseflow with recharge	28.3*	38.8	10.5	+37%
Turbidity (nephelometric turbidity units)	Storm flow	5.3	7	1.7	+32%

*Note: Data for 1981 and 1982 removed from analysis because of effects due to sewer line break

Appendix B - Median concentrations and densities of selected water quality constituents during the rising and falling stages of stormflow for four development classifications within the Barton Springs watershed (Veenhuis and Slade 1990).

Impervious Cover	Dissolved Solids (mg/L)		Suspended Solids (mg/L)		Biochemical Oxygen demand (mg/L)		Total Organic Carbon (mg/L)	
	Rising Stage	Falling Stage	Rising Stage	Falling Stage	Rising Stage	Falling Stage	Rising Stage	Falling Stage
<1%	not detected	245	not detected	6	not detected	0.95	not detected	4
2 to 7%	160	200	508	120	2.7	1.6	14	7.6
9 to 20%	200	180	1280	236	6.2	4.1	29	13
>40%	140	130	1690	410	15	6	38	18

Impervious Cover	Total Nitrogen (mg/L)		Total Phosphorus (mg/L)		Fecal Coliforms (colonies/100 mL)		Fecal Streptococci (colonies/100 mL)	
	Rising Stage	Falling Stage	Rising Stage	Falling Stage	Rising Stage	Falling Stage	Rising Stage	Falling Stage
<1%	not detected	0.5	not detected	0.02	not detected	1000	not detected	1200
2 to 7%	1.6	1.15	0.12	0.05	22000	3700	29000	7600
9 to 20%	3.6	2	0.56	0.26	24500	30000	54000	48000
>40%	4.3	2.15	1.35	0.45	110000	42000	180000	75000

Figure 1

Barton Springs Salamander (*Eurycea sosorum*)

Photo courtesy of C. Riley Nelson

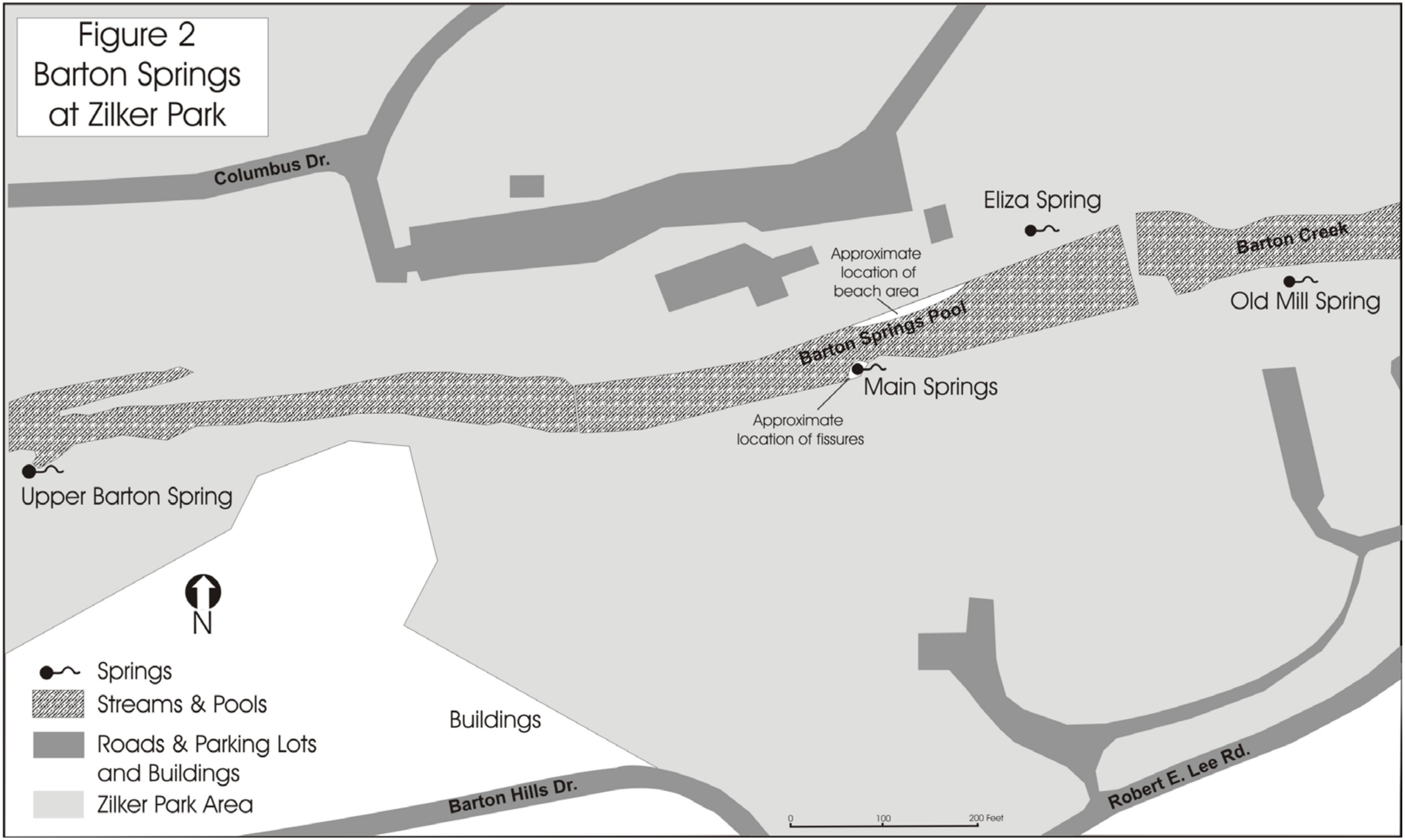
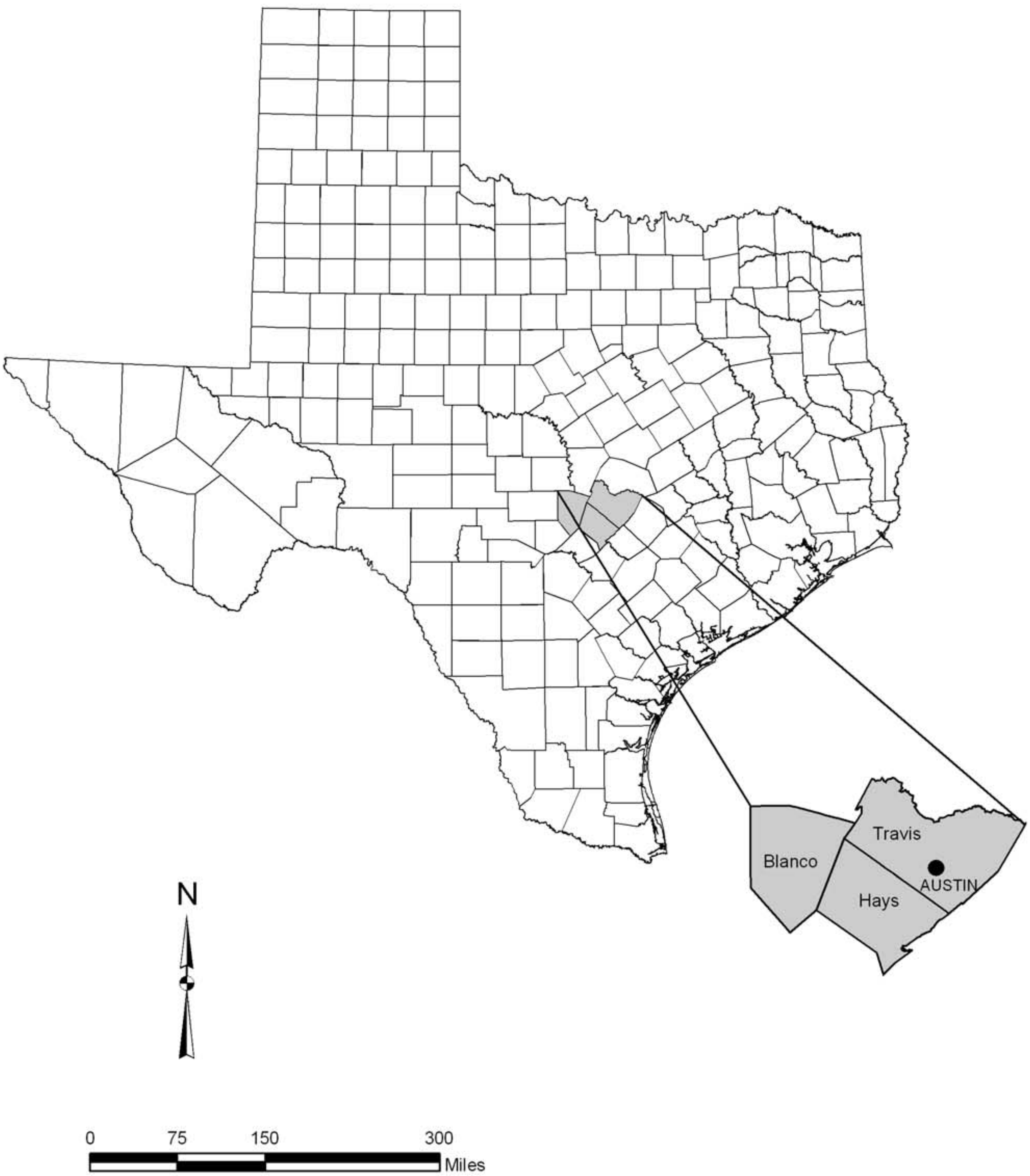


Figure 2
Barton Springs
at Zilker Park
Columbus Dr.
Eliza Spring
Barton Creek
Old Mill Spring
Approximate
location of
beach area
Barton Springs Pool
Main Springs
Approximate
location of fissures
Upper Barton Spring
N
Springs
Streams & Pools
Roads & Parking Lots
and Buildings
Zilker Park Area
Buildings
Barton Hills Dr.
Robert E. Lee Rd.
0
100
200 Feet

Figure 3
Barton Springs - located in the City of Austin, Travis County, Texas



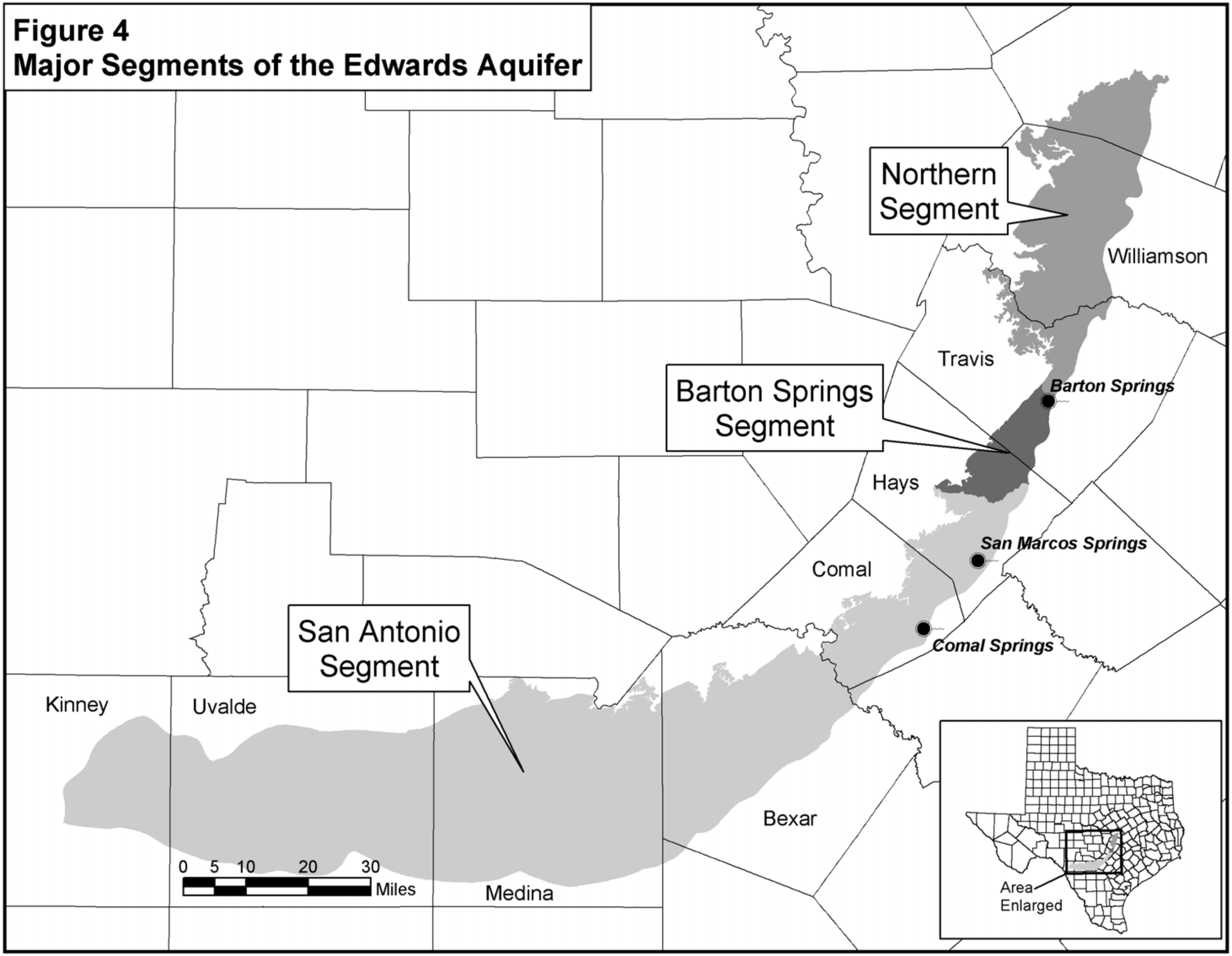


Figure 4
Major Segments of the Edwards Aquifer
Northern Segment
Williamson
Travis
Barton Springs Segment
Barton Springs
Hays
San Marcos Springs
Comal
Comal Springs
San Antonio Segment
Kinney
Uvalde
Medina
Bexar
0 5 10 20 30
Miles
Area Enlarged

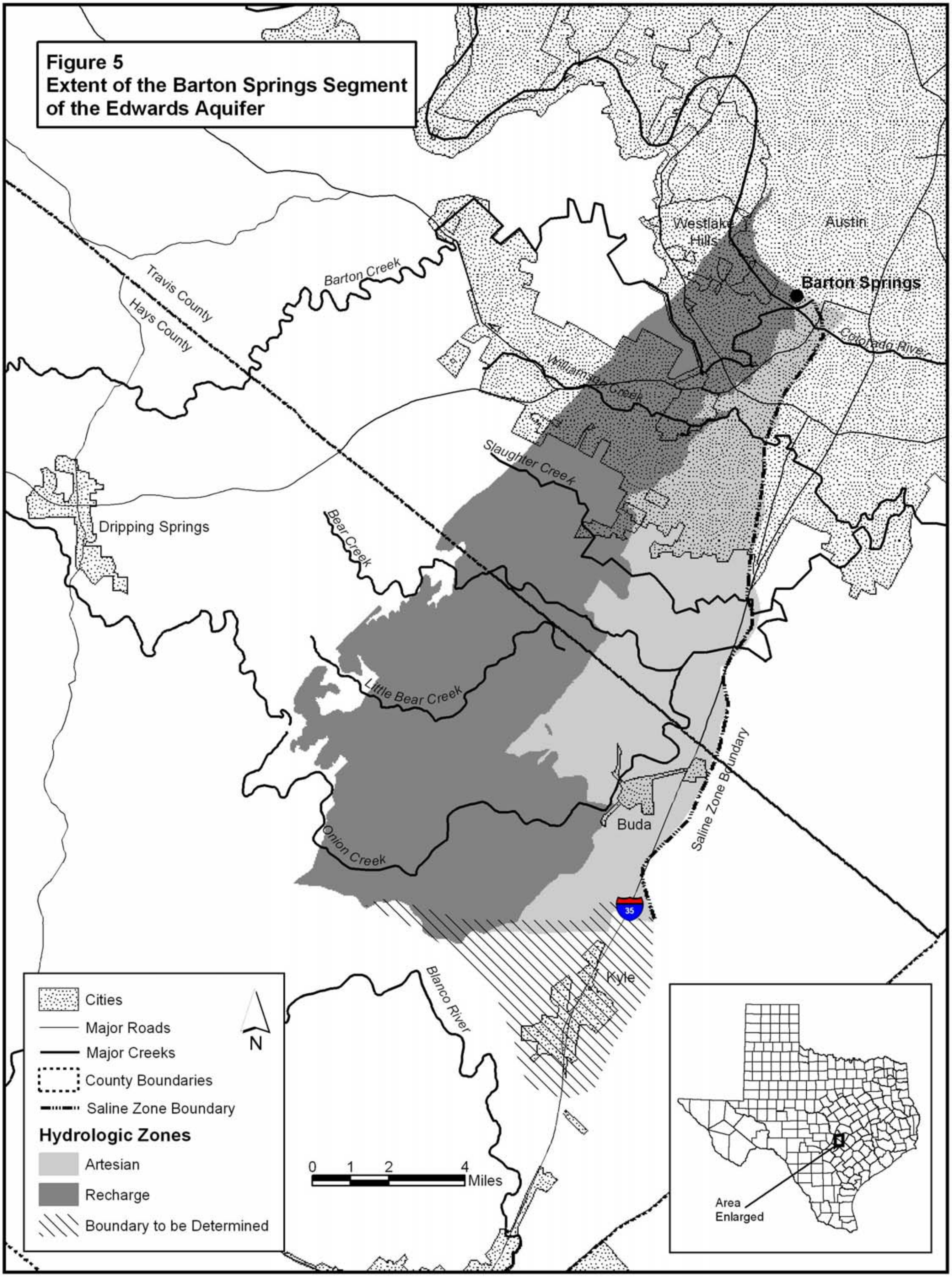


Figure 5
Extent of the Barton Springs Segment of the Edwards Aquifer
Westlake Hills
Austin
Barton Springs
Colorado River
Barton Creek
Travis County
Hays County
Williamson Creek
Slaughter Creek
Dripping Springs
Bear Creek
Little Bear Creek
Onion Creek
Buda
Saline Zone Boundary
35
Kyle
Blanco River
Cities
Major Roads
Major Creeks
County Boundaries
Saline Zone Boundary
Hydrologic Zones
Artesian
Recharge
Boundary to be Determined
N
0 1 2 4 Miles
Area Enlarged

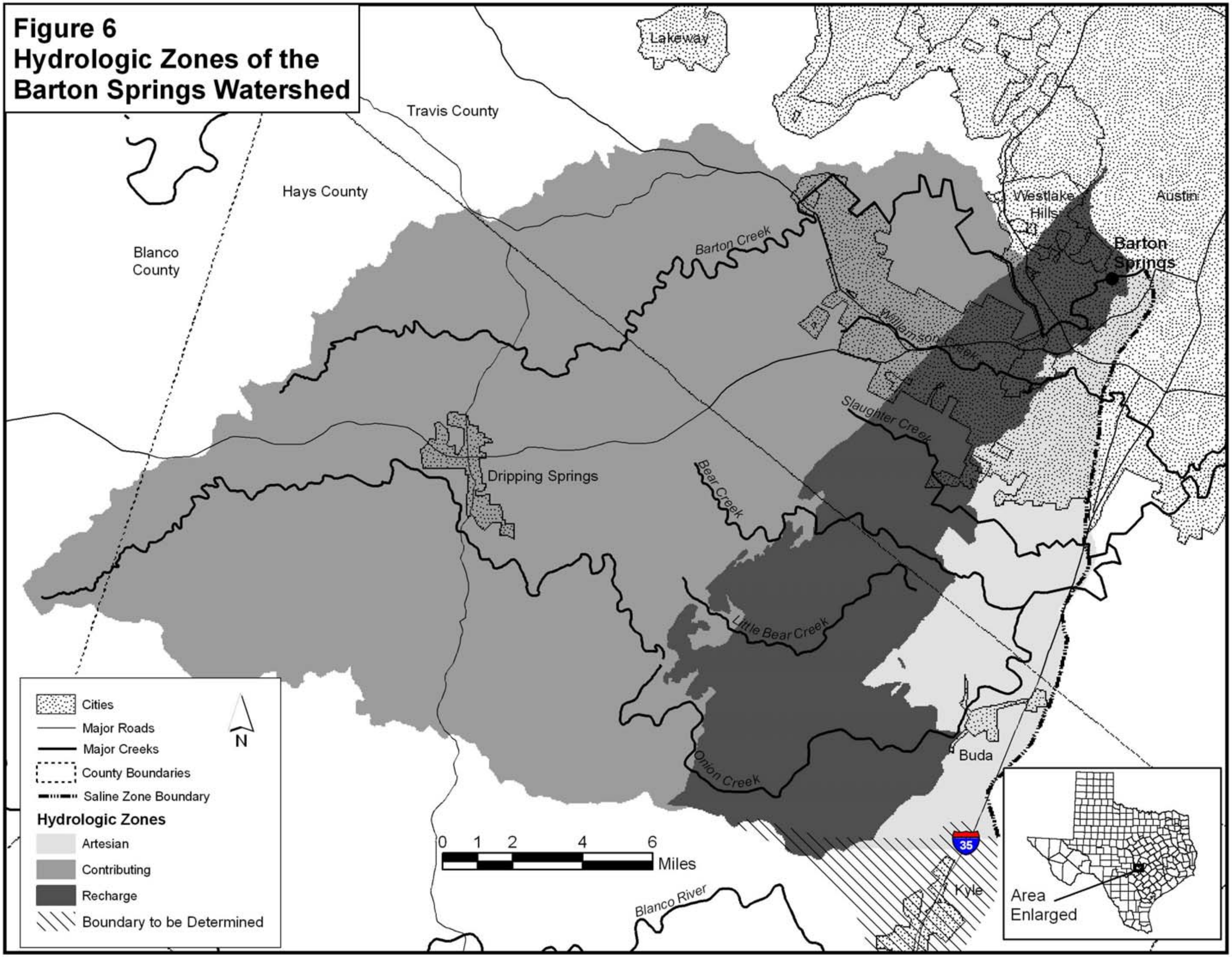


Figure 6
Hydrologic Zones of the
Barton Springs Watershed
Lakeway
Travis County
Hays County
Blanco
County
Westlake
Hills
Austin
Barton
Springs
Barton Creek
Williamson Creek
Slaughter Creek
Dripping Springs
Bear Creek
Little Bear Creek
Onion Creek
Buda
Kyle
Blanco River
35
0 1 2 4 6
Miles
N
Cities
Major Roads
Major Creeks
County Boundaries
Saline Zone Boundary
Hydrologic Zones
Artesian
Contributing
Recharge
Boundary to be Determined
Area
Enlarged

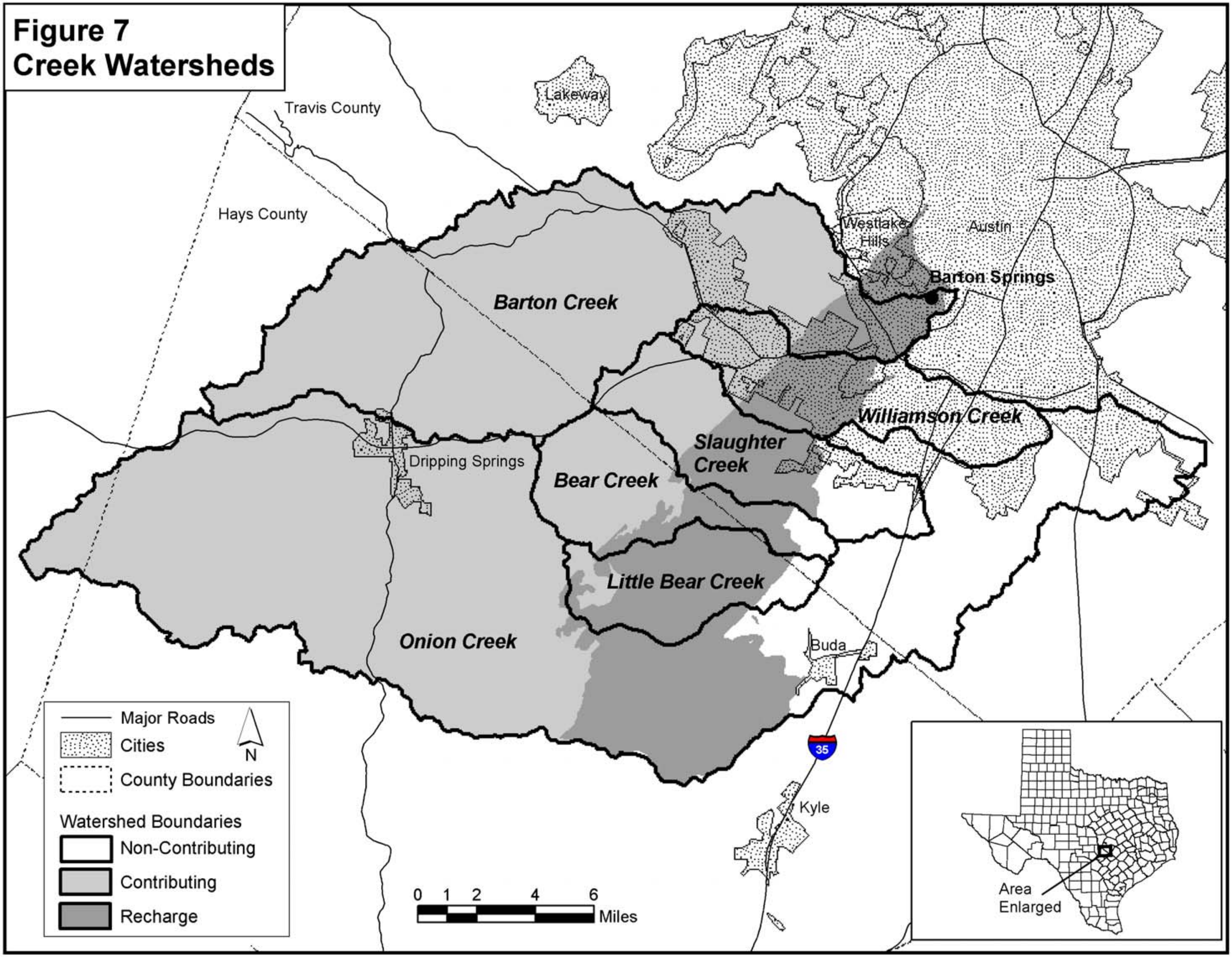
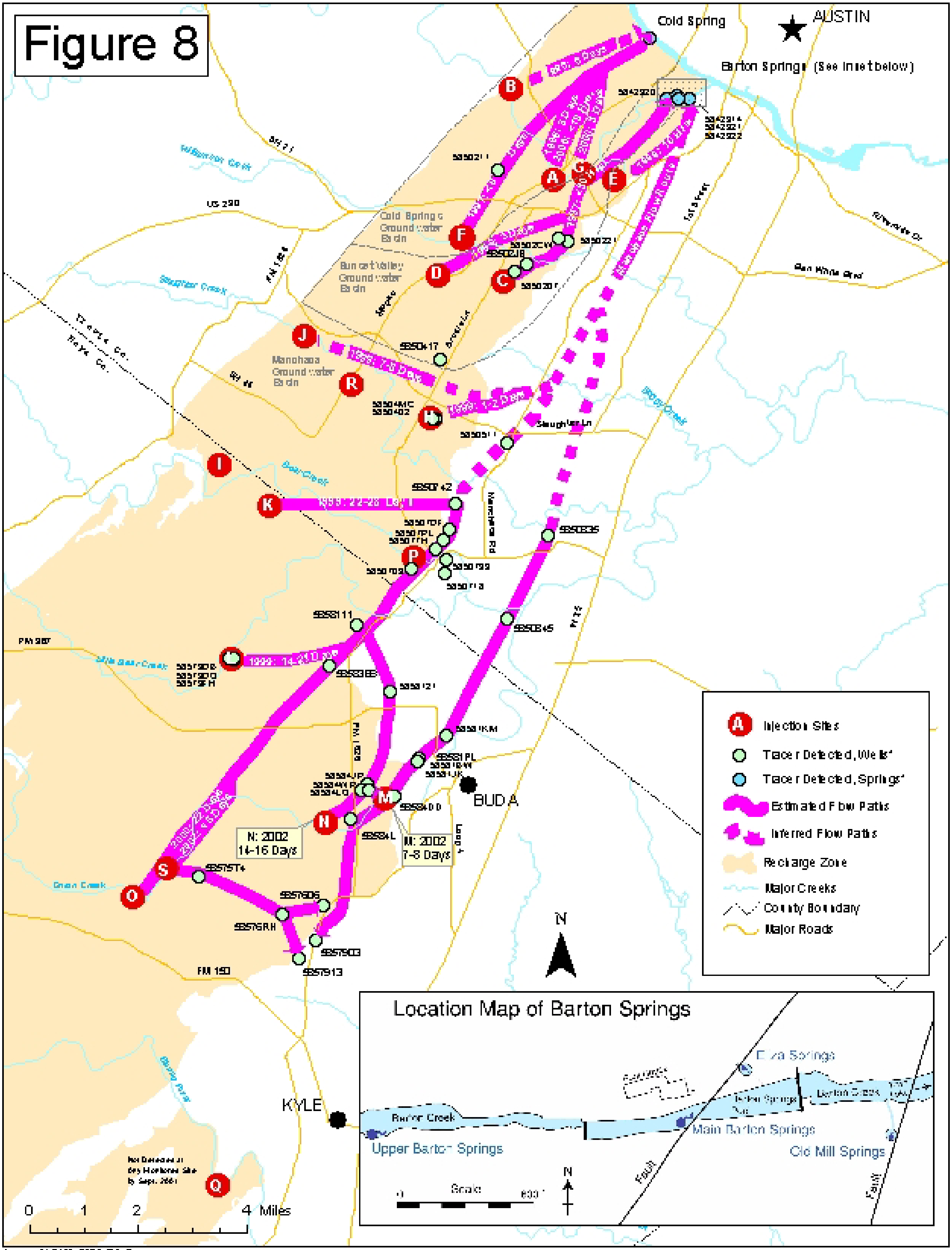


Figure 7
Creek Watersheds
Travis County
Hays County
Lakeway
Westlake Hills
Austin
Barton Springs
Barton Creek
Williamson Creek
Slaughter Creek
Bear Creek
Dripping Springs
Little Bear Creek
Onion Creek
Buda
Kyle
35
Major Roads
Cities
County Boundaries
Watershed Boundaries
Non-Contributing
Contributing
Recharge
N
0 1 2 4 6
Miles
Area Enlarged



* Monitored wells and springs with no detections are not shown.
** All travel times are to the Springs (Cold Spring and Barton Springs).

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Cover photography by Lisa O'Donnell, City of Austin

January 2005